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HANFORD SITE NATIONAL ENVIRONMENTAL POLICY ACT (NEPA) CHARACTERIZATION

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C. E. Cushing, Editor

September 1988

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Richland, Washington 99352

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FOREWORD

This document describes the Hanford Site environment (Chapter 4) and contains data in Chapters 5 and 6 which will guide users in the preparation of National Environmental Policy Act (NEPA)-related documents.

Many NEPA compliance documents have been prepared and are being prepared by site contractors for the U.S. Department of Energy, and examination of these documents reveals inconsistencies in the amount of detail presented and the method of presentation. Thus, it seemed necessary to prepare a consistent description of the Hanford environment to be used in preparing Chapter 4 of environmental impact statements and other site-related NEPA documentation. The material in Chapter 5 is a guide to the models used, including critical assumptions incorporated in these models, in previous Hanford NEPA documents. The user will have to select those models appropriate for the proposed action. Chapter 6 is essentially a definitive NEPA Chapter 6, which describes the applicable laws, regulations, and DOE and state orders.

In this document, a complete description of the environment is presented in Chapter 4 without extensive tabular data. For these data, sources are provided. Most subjects are divided into a general description of the characteristics of the Hanford Site, followed by site-specific information where it is available on the 100, 200, 300, and other Areas. This division will allow a person requiring information to go immediately to those sections of particular interest. However, site-specific information on each of these separate areas is not always complete or available. In this case, the general Hanford Site description should be used.

One other aspect of this document requires comment. Certain subjects covered (e.g., threatened and endangered species, Tri-Cities populations) are more likely to change than others. Therefore, this document should be updated periodically. Thus, the user should be aware that the greater the time between publication of this latest revision (September 1988) and the time it is being used, the greater the likelihood of changes taking place. To enhance the usability of the document, particularly for those aspects not likely to change, a copy of the entire text is furnished on an IBM-PC diskette in WordPerfect 4.2 with each copy of the controlled document. The document has been distributed to personnel of the Operations and Engineering Contractor (Westinghouse Hanford Company), the Research and Development Contractor (Pacific Northwest Laboratory), and the U.S. Department of Energy. (Note: the figures can be obtained by contacting Dan Foley in the BCSR graphics department located in the PNL Research Operations Building.)

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HANFORD SITE NATIONAL ENVIRONMENTAL POLICY ACT (NEPA) CHARACTERIZATION

Chapter 4: Affected Environment

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4.0 AFFECTED ENVIRONMENT

The U.S. Department of Energy's Hanford Site lies within the semiarid Pasco Basin of the Columbia Plateau in southeastern Washington State (Figure 4.0-1). The Hanford Site occupies an area of about 1450 km^2 north of the confluence of the Snake and Yakima rivers with the Columbia River. The Hanford Site is about 50 km north to south and 40 km east to west. This land, with restricted public access, provides a buffer for the smaller areas currently used for production of nuclear materials, waste storage, and waste disposal; only about 6% of the land area has been disturbed and is actively used. The Columbia River flows through the northern part of the Hanford Site, and turning south, it forms part of its eastern boundary. The Yakima River runs along part of the southern boundary and joins the Columbia River below the city of Richland, which bounds the Hanford Site on the southeast. Rattlesnake Mountain, the Yakima Ridge, and the Umtanum Ridge form the southwestern and western boundary. The Saddle Mountains form the northern boundary of the Hanford Site. Two small east-west ridges, Gable Butte and Gable Mountain, rise above the plateau of the central part of the Hanford Site. Adjoining lands to the west, north, and east are principally range and agricultural land (Figure 4.0-2). The cities of Richland, Kennewick, and Pasco (Tri-Cities) comprise the nearest population center and are located southeast of the Hanford Site.

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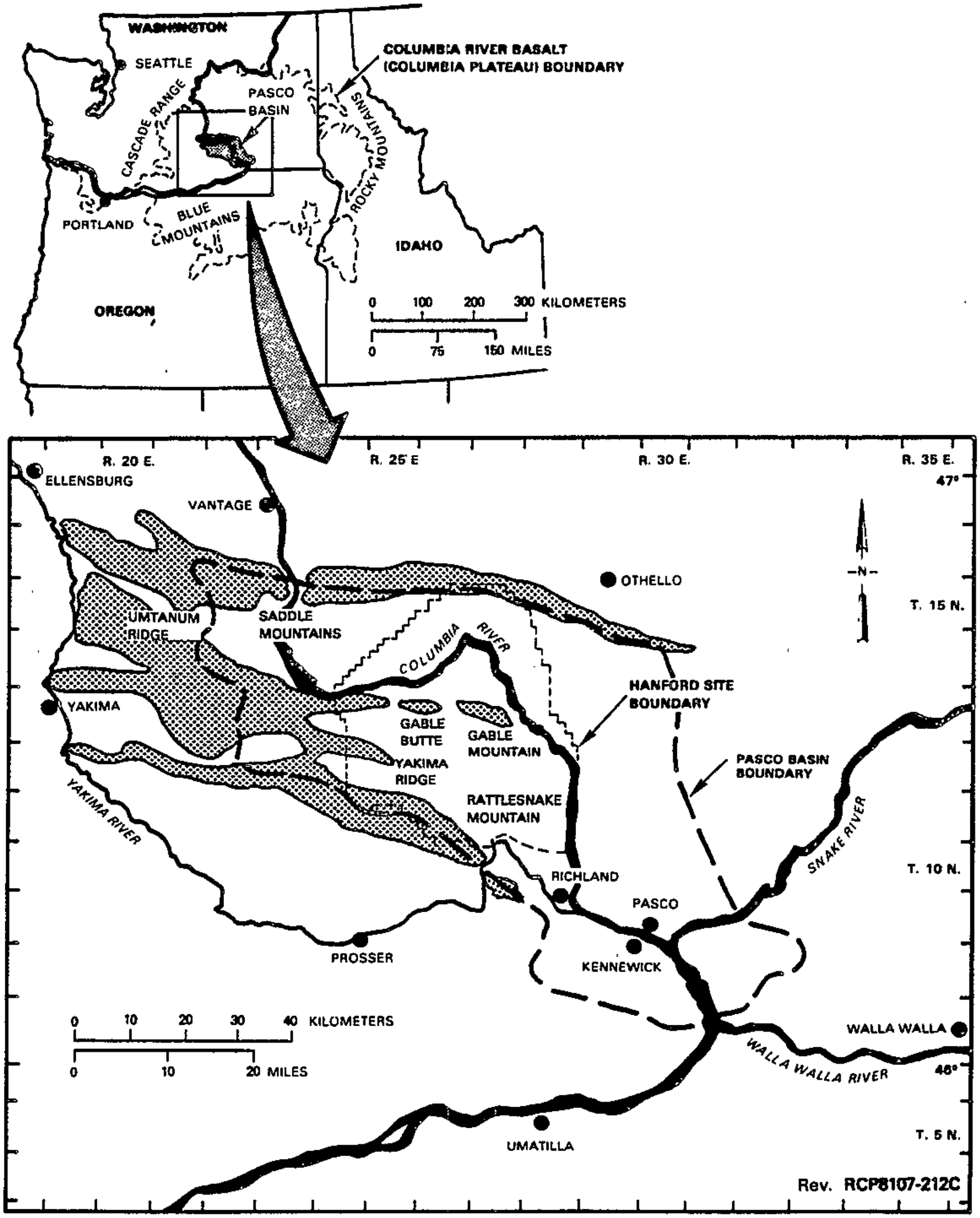

FIGURE 4.0-1. Hanford Site and Environs

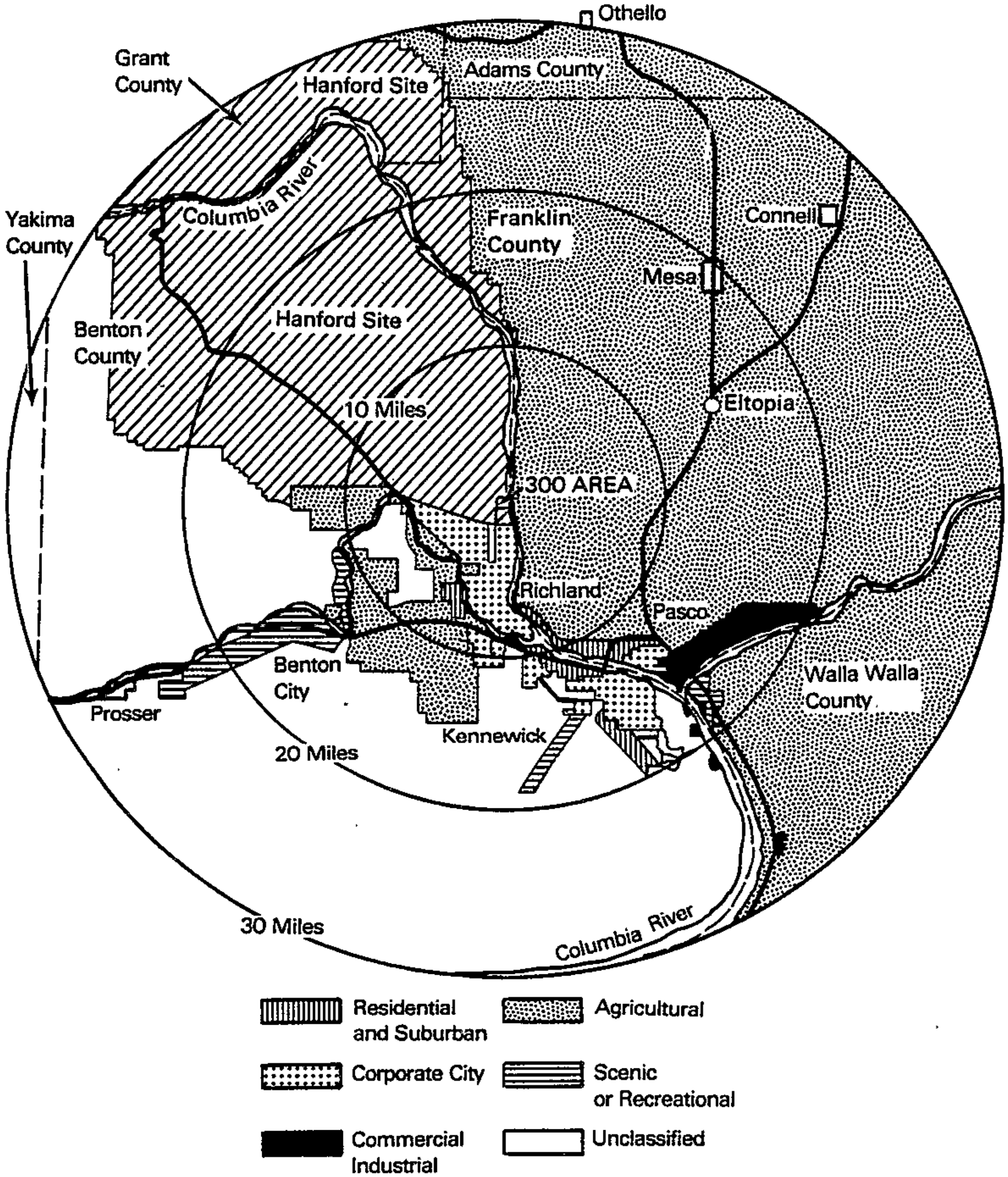

FIGURE 4.0-2. Zoning Status of Area Surrounding the Hanford Site

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4.1 CLIMATE AND METEOROLOGY

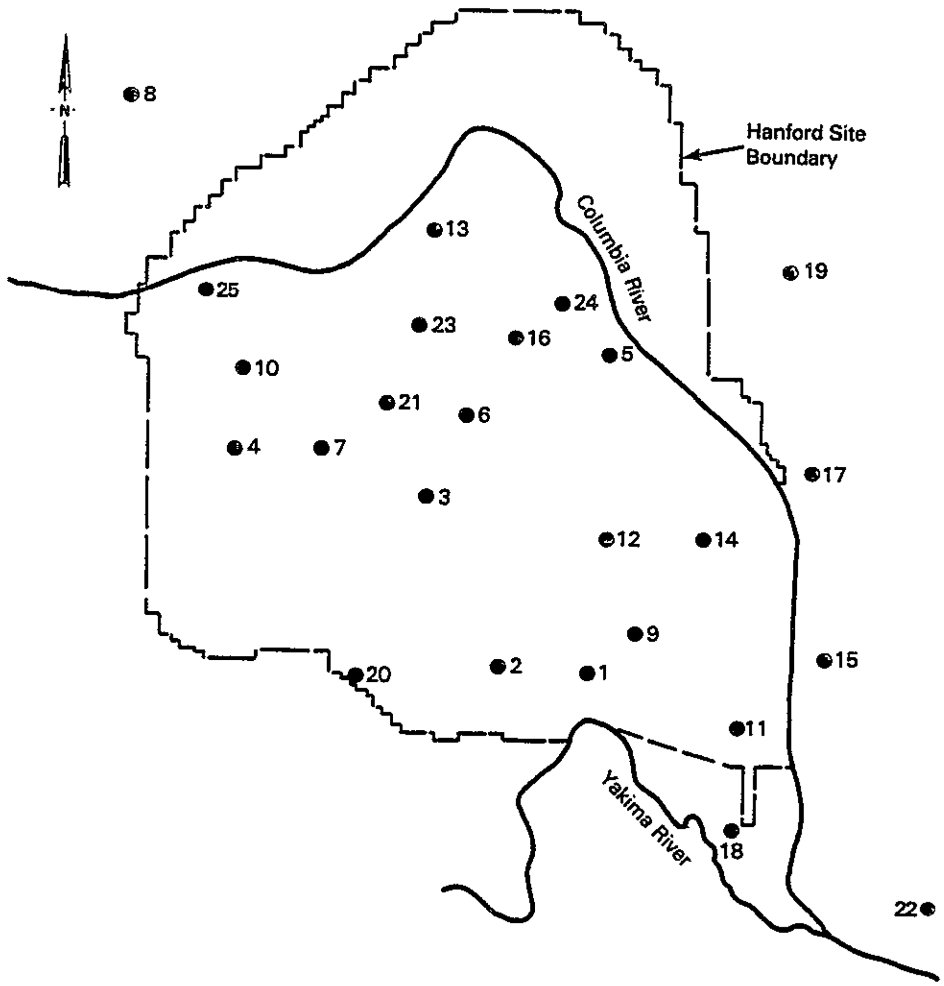
The Hanford Site is located in a semiarid region of southeastern Washington State. The Cascade Mountains beyond Yakima to the west greatly influence the climate of the Hanford Area due in part to the rain shadow effect of this range and also by serving as a source of cold air drainage, which has a considerable effect on the wind regime on the Hanford Site.

Climatological data are available for the Hanford Meteorological Station (HMS), which is located between the 200 Areas. Data have been collected at this location since 1945. Temperature and precipitation data are also available from nearby locations for the period 1912 through 1943. A summary of these data through 1980 has been published by Stone et al. (1983). Data from the HMS are representative of the general climatic conditions for the region and describe the specific climate of the 200-Area Plateau. There are local variations in the topography of the Hanford Site that may cause some aspects of climate at portions of the Hanford Site to differ significantly from those of the HMS. For example, winds near the Columbia River are different than those at the HMS. Similarly, precipitation along the slopes of the Rattlesnake Hills differ climatically from that at the HMS.

4.1.1 Wind

Wind data are collected at the HMS at the surface (2.1 m above the ground) and at the 15.2-, 30.5-, 61.0-, 91.4-, and 121.9-m levels of a 125-m tower. Three 60-m towers, with wind measuring instrumentation at the 10-, 25-, and 60-m levels, are located at the primary operating areas (300, 400, and 100-N Areas). In addition, wind instruments on twenty-one 9.1-m towers distributed on and around the Hanford Site (Figure 4.1-1) provide supplementary data for defining wind patterns.

Prevailing wind directions on the 200-Area Plateau are from the northwest in all months of the year (Figure 4.1-2). Secondary maxima occur for southwesterly winds. Summaries of wind direction indicate that winds from the northwest quadrant occur most often during the winter and summer. During the spring and fall, the frequency of southwesterly winds increases with a corresponding decrease in northwest flow. Winds blowing from other directions (e.g., northeast) display minimal variation from month to month.



Station No.	Station Name	Station No.	Station Name
1	Prosser Barricade	14	WPPSS
2	EOC	15	Franklin County
3	Army Loop Road	16	Gable Mountain
4	Rattlesnake Springs	17	Ringold
5	Edna	18	Richland Arpt
6	200-East	19	Sagehill
7	200-West (BWIP)	20	Rattlesnake Mtn
8	Wahluke Slope	21	HMS (121.9-m)
9	FFTF (60-m)	22	Pasco Arpt
10	Yakima Barricade	23	Gable West
11	300-Area (60-m)	24	100-F
12	Wye Barricade	25	Vernita
13	100-N (60-m)		

NOTE: All network stations are 9.1 m unless otherwise indicated.

FIGURE 4.1-1. Hanford Site Wind Monitoring Network

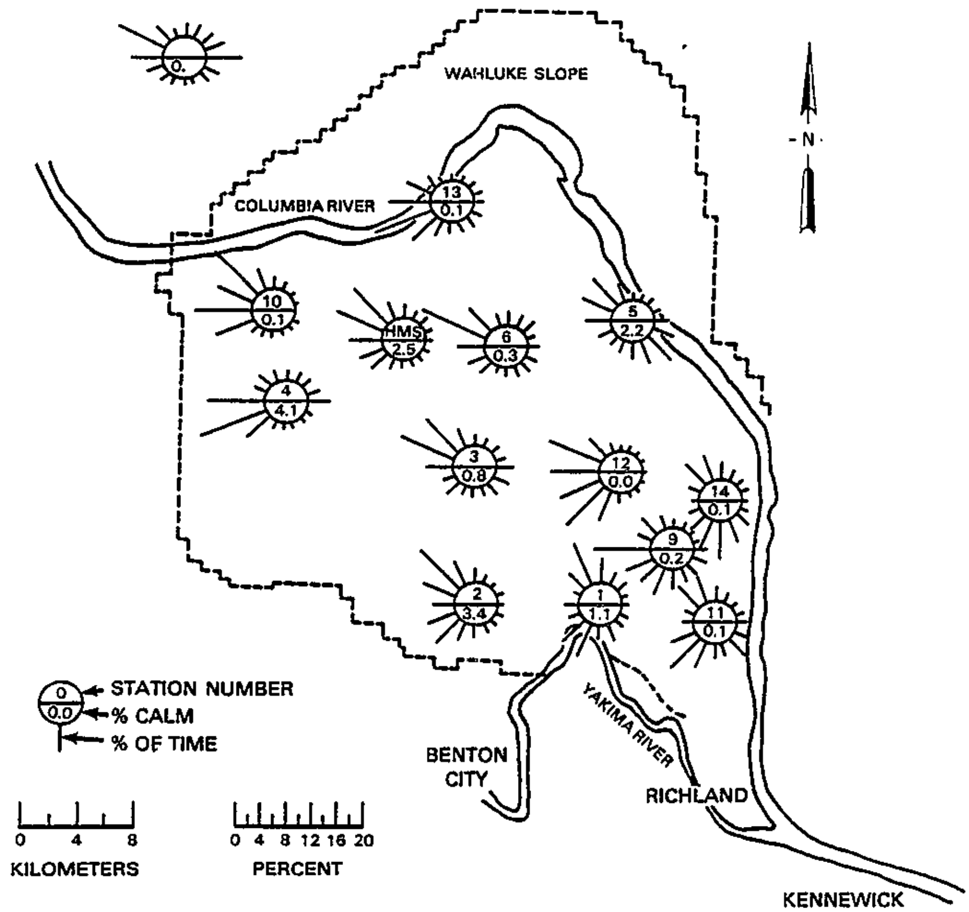


FIGURE 4.1-2. Wind Roses for the Hanford Telemetry Network, 1979-1982. The point of each rose represents the directions from which the winds come (Stone et al. 1983).

Monthly and annual joint frequency distributions of wind direction versus wind speed for the HMS are given in Stone et al. (1983). Monthly average wind speeds are lowest during the winter months, averaging 10 to 11 km/h, and highest during the summer, averaging 14 to 16 km/h. Wind speeds that are well above average are usually associated with southwesterly winds. However, the summertime drainage winds are generally northwesterly and frequently reach 50 km/h. These winds are most prevalent over the northern portion of the Hanford Site.

High winds are also associated with thunderstorms. The average occurrence of thunderstorms is 10 per year. They are most frequent during the summer; however, they have occurred in each month. The average winds during thunderstorms do not come from any specific direction. Estimates of the extreme winds, based on peak gusts observed from 1945 through 1980, are given in Stone et al. (1983) and are shown in Table 4.1-1. Using the National Weather Service criteria for classifying a thunderstorm as "severe," (i.e., hail with a diameter equal to or greater than 20 mm or wind gusts of 93 km/h or greater) only 1.9% of all thunderstorm events observed at the HMS have been "severe" storms, and all met the criteria based upon wind gusts.

Tornados are infrequent and generally small in the northwest portion of the United States. Grazulis (1984) lists no violent tornados for the region surrounding Hanford (DOE 1986a). The HMS climatological summary (Stone et al. 1983) and the National Severe Storms Forecast Center (NSSFC) data base list 22 separate tornado occurrences within 161 km of the Hanford Site from 1916 through August 1982. Two additional tornados have been reported since August 1982.

Using the information in the preceding paragraph and the statistics published in Ramsdell and Andrews (1986) for the 5° block centered at 117.5° west longitude and 47.5° north latitude (the area in which the Hanford Site is located), the expected path length of a tornado on the Hanford Site is 7.6 km, the expected width is 95 m, and the expected area is about 1.5 km^2. Also from Ramsdell and Andrews (1986) the estimated probability of a tornado striking a point at Hanford is 9.6×10^{-6}/yr. The probabilities of extreme winds associated with tornadoes striking a point can be estimated using the distribution of tornado intensities for the region. These probability estimates are given in Table 4.1-2.

TABLE 4.1-1. Estimates of Extreme Winds at Hanford Site

Return Period, yr	Peak Gusts, km/h 15.2 m Above Ground	Peak Gusts, km/h 61 m Above Ground
2	97	109
10	114	129
100	137	151
1000	159	175

TABLE 4.1-2. Estimate of the Probability of Extreme Winds Associated with Tornados Striking a Point at Hanford (Ramsdell and Andrews 1986)

Wind Speed, km/h	Probability Per Year
100	2.6×10^{-6}
200	6.5×10^{-7}
300	1.6×10^{-7}
400	3.9×10^{-8}

4.1.2 Temperature and Humidity

Temperature measurements are made at the 0.9-, 9.1-, 15.2-, 30.5-, 61.0-, 76.2- 91.4- and 121.9-m levels of the 125-m tower at the HMS. As of May 1987, temperatures are also measured at the 2-m level on the twenty-one 9.1-m towers located on and around the Hanford Site. The three 60-m towers have temperature measuring instrumentation at the 2-, 10- and 60-m levels. The temperature data from the 9.1- and 60-m towers are telemetered to the HMS.

Diurnal and monthly averages and extremes of temperature, dew point, and humidity are contained in Stone et al. (1983). Ranges of daily maximum and minimum temperatures vary from normal maxima of 2°C in early January to 35°C in late July. There are, on the average, 55 days during the summer months with maximum temperatures greater than or equal to 32°C and 13 days with maxima greater than or equal to 38°C. From mid-November through mid-March, minimum temperatures average less than or equal to 0°C with the minima in early January averaging -6°C. During the winter, there are an average of 4 days with minimum temperatures less than or equal to -18°C; however, only about one winter in two experiences such temperatures. The record maximum temperature is 46°C, and the record minimum temperature is -32.8°C. For the period 1912 through 1980, the average monthly temperatures range from a low of -1.5°C in January to a high of 24.7°C in July. During the winter, the highest monthly average temperature at the HMS was 6.9°C, and the record lowest was -5.9°C; both having occurred during February. During the summer, the record maximum monthly average temperature was 27.9°C (in July), and the record lowest was 17.2°C (in June).

Relative humidity/dew point temperature measurements are made at the HMS and at the three 60-m tower locations. The annual average relative humidity at the Hanford Meteorological Station is 54%. It is highest during the winter months, averaging about 75%, and lowest during the summer, averaging about 35%. Wet bulb temperatures greater than 24°C had not been observed at the HMS prior to 1975; however, on July 8, 9, and 10 of that year, there were seven hourly observations with wet bulb temperatures greater than or equal to 24°C.

4.1.3 Precipitation

Precipitation measurements have been made at the HMS since 1945. Average annual precipitation at the HMS is 16 cm. Most of the precipitation occurs during the winter with nearly half of the annual amount occurring in the months of November through February. Days with greater than 1.3 cm precipitation occur less than 1% of the year. Rainfall intensities of 1.3 cm/h persisting for 1 hour are expected once every 10 years. Rainfall intensities of 2.5 cm/h for 1 hour are expected only once every 500 years. Winter monthly average snowfall ranges from 0.8 cm in March to 13.5 cm in January. The record snowfall of 62 cm occurred in February 1916. Snowfall accounts for about 38% of all precipitation during the months of December through February.

In the spring of 1987, precipitation measurements for four other locations (Rattlesnake Mountain, Richland Airport, Rattlesnake Springs, and Yakima Barricade) were added to the meteorological measurement system. Climatological precipitation measurements have also been made on the Arid Lands Ecology Reserve on the western slope of the Rattlesnake Hills (Stone et al. 1983).

4.1.4 Atmospheric Dispersion

Atmospheric dispersion is a function of wind speed, atmospheric stability, and mixing depth. Dispersion conditions are generally good if winds are moderate to strong, the atmosphere is of neutral or unstable stratification, and there is a deep mixing layer. Good dispersion conditions associated with neutral and unstable stratification exist about 57% of the time during the summer. Less favorable dispersion conditions may occur when the wind speed is light and the mixing layer is shallow. These conditions are most common during the winter when moderately to extremely stable stratification exists about 66% of the time. Less favorable conditions also occur periodically for surface and low-level releases in all seasons from about sunset to about an hour after sunrise as a result of ground-based temperature inversions and shallow mixing layers.

Occasionally there are extended periods of poor dispersion conditions that are associated with stagnant air in stationary high-pressure systems that occur primarily during the winter months. Stone et al. (1972) estimated the probability of extended periods of poor dispersion conditions. The probability of an inversion period extending more than 12 hours varies from a low of about 10% in May and June to a high of about 64% in September and October. These probabilities decrease rapidly for durations of greater than 12 hours. Table 4.1-3 summarizes the probabilities associated with extended surface-based inversions.

4.1.5 Air Quality

Air quality in the vicinity of the Hanford Site is generally classified as quite good. The Benton-Franklin/Walla Walla Counties Air Pollution Control Authority routinely monitors total suspended particulate concentrations at the HMS. No other pollutants are routinely monitored by this agency.

Wind-eroded dust, resulting from plowed fields and arid terrain with sparse vegetation, is an occasional problem in the area. On a short-term

TABLE 4.1-3. Percent Probabilities for Extended Periods of Surface-Based Inversions

Months	Inversion Duration		
	12 h	24 h	48 h
January-February	54.0	2.5	0.28
March-April	50.0	<0.1	<0.1
May-June	10.0	<0.1	<0.1
July-August	18.0	<0.1	<0.1
September-October	64.0	0.11	<0.1
November-December	50.0	1.2	0.13

basis, the dust storms that occur can produce high concentrations of total suspended particulates. The atmospheric conditions that produce the dust are otherwise favorable to pollutant transport and diffusion.

The discussion of air quality in the Skagit/Hanford Draft Environmental Impact Statement (NRC 1982) reflects the current conditions in the Columbia Basin, except for nitrogen oxides. The PUREX facility, which releases nitrogen oxides, was inactive from 1972 until resuming operation in November 1983 (DOE 1982b). This facility releases nitrogen oxides under the terms of a Prevention of Significant Deterioration permit.

Ambient nitrogen oxide measurements made by the Hanford Environmental Health Foundation (HEHF) before the restart of PUREX (1983) indicated that the background concentration was less than seven parts per billion. Monitoring is continuing; the maximum annual average concentration for 1984 was less than eight parts per billion.

4.1.6 100 Areas

The surface wind pattern at the 100-N Area is greatly affected by the topographic influence of the Columbia River. The wind rose for station 13 (Figure 4.1-2) shows a prevailing wind direction from the west-southwest (along the river) at the 10-m level. The 60-m tower at the 100-N Area provides additional data to define the wind at 60-m, which is influenced less by surface features than the 10-m instrument. However, because this tower is relatively new (1986), data are currently being collected and will not be available until 1989.

Temperature measurements for this area were also initiated at the time that the 60-m tower was erected. Temperature difference measurements between the 60-m and 10-m levels provide information for determining atmospheric stability, a parameter important to atmospheric dispersion calculations. These data are being collected and will be available in 1989. In the interim, the χ/Q values in Table 4.1-4 may be used.

TABLE 4.1-4. Annual Average Atmospheric Dispersion Around the 100-N Area for an 82-m Release Height (Units are s/m^3)[(a)] (After Sula et al. 1982, Table E.5.)

	Range, mi (km)									
Direction	0.5 (0.8)	1.5 (2.4)	2.5 (4.0)	3.5 (5.6)	4.5 (7.2)	7.5 (2.0)	15 (24)	25 (40)	35 (56)	45 (72)
N	3.68E-08	1.60E-08	9.02E-09	5.69E-09	4.05E-09	2.49E-09	1.91E-09	1.44E-09	1.10E-09	8.69E-10
NNE	5.24E-08	2.05E-08	1.08E-08	6.64E-09	4.62E-09	2.68E-09	1.94E-09	1.46E-09	1.12E-09	8.90E-10
NE	1.44E-09	4.84E-08	2.35E-08	1.39E-08	9.39E-09	5.02E-09	3.30E-09	2.44E-09	1.87E-09	1.48E-09
ENE	1.21E-07	5.50E-08	2.81E-08	1.70E-08	1.17E-08	6.65E-09	4.72E-09	3.56E-09	2.73E-09	2.17E-09
E	1.14E-09	6.79E-08	3.60E-08	1.54E-08	9.31E-09	7.43E-09	5.95E-09	5.95E-09	4.70E-09	3.79E-09
ESE	1.20E-07	7.12E-08	3.76E-08	2.29E-08	1.59E-08	9.18E-09	6.87E-09	5.41E-09	4.27E-09	3.45E-09
SE	7.91E-08	4.84E-08	2.60E-08	1.60E-08	1.10E-08	5.95E-09	3.81E-09	2.74E-09	2.07E-09	1.63E-09
SSE	7.94E-08	4.40E-08	2.27E-08	1.37E-08	9.28E-09	4.73E-09	2.72E-09	1.85E-09	1.36E-09	1.05E-09
S	9.41E-08	4.26E-08	2.14E-08	1.27E-08	8.58E-09	4.25E-09	2.32E-09	1.55E-09	1.13E-09	8.70E-10
SSW	1.61E-07	5.84E-08	2.82E-08	1.65E-08	1.10E-08	5.38E-09	2.89E-09	1.93E-09	1.41E-09	1.09E-09
SW	7.78E-08	3.33E-08	1.77E-08	1.08E-08	7.49E-09	4.13E-09	2.67E-09	1.89E-09	1.41E-09	1.10E-09
WSW	5.39E-08	2.74E-08	1.62E-08	1.04E-08	7.39E-09	4.34E-09	2.99E-09	2.14E-09	1.59E-09	1.24E-09
W	7.20E-08	3.48E-08	1.97E-08	1.25E-08	8.81E-09	5.20E-09	3.64E-09	2.62E-09	1.95E-092	1.52E-09
WNW	8.53E-08	3.75E-08	2.07E-08	1.29E-08	0.02E-09	5.09E-09	3.39E-09	2.41E-09	1.80E-09	1.40E-09
NW	8.32E-08	3.48E-08	1.90E-08	1.18E-08	8.24E-09	4.62E-09	3.60E-09	2.19E-08	1.64E-09	1.28E-09
NNW	4.68E-08	2.07E-08	1.18E-08	7.43E-09	5.22E-09	2.99E-09	2.04E-09	1.48E-09	1.11E-09	8.69E-10

(a) Calculated from meteorological data collected for the period 2-70 through 1-71.

4.1.7 200 Areas

Data from the HMS is used to calculate atmospheric dispersion factors as a function of distance and compass direction. Annual average values are presented in Table 4.1-5. These dispersion factors are used to estimate the downwind air concentrations of emissions routinely released into the environment.

Accidental releases use more stringent meteorological assumptions usually termed 95 percentile probabilities. Sector-averaged and center line χ/Q for acute ground level and elevated releases are presented in Tables 4.1-6 through 4.1-9.

TABLE 4.1-5. Annual Average Atmospheric Dispersion Parameters, $\bar{\chi}/Q'$ (s/m^3) Values, for Elevated Releases[a] from the 200 Areas[b]

	Range, mi (km)									
Direction	0.5 (0.8)	1.5 (2.4)	2.5 (4.0)	3.5 (5.6)	4.5 (7.2)	7.5 (12)	15 (24)	25 (40)	35 (56)	45 (72)
N	5.59×10^{-8}	4.78×10^{-8}	3.80×10^{-8}	2.96×10^{-8}	2.36×10^{-8}	1.48×10^{-8}	7.32×10^{-9}	4.30×10^{-9}	3.02×10^{-9}	2.33×10^{-9}
NNE	3.82×10^{-8}	3.20×10^{-8}	2.50×10^{-8}	1.94×10^{-8}	1.55×10^{-8}	9.61×10^{-9}	4.75×10^{-9}	2.78×10^{-9}	1.94×10^{-9}	1.50×10^{-9}
NE	5.17×10^{-8}	3.75×10^{-8}	2.81×10^{-8}	2.14×10^{-8}	1.69×10^{-8}	1.03×10^{-8}	4.98×10^{-9}	2.89×10^{-9}	2.01×10^{-9}	1.55×10^{-9}
ENE	5.97×10^{-8}	4.91×10^{-8}	3.85×10^{-8}	2.99×10^{-8}	2.38×10^{-8}	1.48×10^{-8}	7.27×10^{-9}	4.26×10^{-9}	2.98×10^{-9}	2.30×10^{-9}
E	6.26×10^{-8}	7.19×10^{-8}	6.09×10^{-8}	4.91×10^{-8}	3.97×10^{-8}	2.57×10^{-8}	1.31×10^{-8}	7.83×10^{-9}	5.54×10^{-9}	4.31×10^{-9}
ESE	7.44×10^{-8}	8.62×10^{-8}	7.30×10^{-8}	5.84×10^{-8}	4.71×10^{-8}	2.99×10^{-8}	1.51×10^{-8}	8.94×10^{-9}	6.30×10^{-9}	4.89×10^{-9}
SE	1.23×10^{-7}	1.21×10^{-7}	9.55×10^{-8}	7.45×10^{-8}	5.93×10^{-8}	3.70×10^{-8}	1.83×10^{-8}	1.07×10^{-8}	7.50×10^{-9}	5.79×10^{-9}
SSE	1.15×10^{-7}	9.68×10^{-8}	7.34×10^{-8}	5.61×10^{-8}	4.43×10^{-8}	2.71×10^{-8}	1.31×10^{-8}	7.61×10^{-9}	5.30×10^{-9}	4.08×10^{-9}
S	1.54×10^{-7}	1.19×10^{-7}	8.74×10^{-8}	6.56×10^{-8}	5.12×10^{-8}	3.05×10^{-8}	1.44×10^{-8}	8.20×10^{-9}	5.66×10^{-9}	4.32×10^{-9}
SSW	1.22×10^{-7}	9.24×10^{-8}	6.37×10^{-8}	4.61×10^{-8}	3.53×10^{-8}	2.01×10^{-8}	8.99×10^{-9}	4.94×10^{-9}	3.35×10^{-9}	2.52×10^{-9}
SW	9.56×10^{-8}	6.68×10^{-8}	4.63×10^{-8}	3.37×10^{-8}	2.59×10^{-8}	1.48×10^{-8}	6.73×10^{-9}	3.74×10^{-9}	2.55×10^{-9}	1.92×10^{-9}
WSW	7.30×10^{-8}	5.93×10^{-8}	4.29×10^{-8}	3.17×10^{-8}	2.46×10^{-8}	1.43×10^{-8}	6.57×10^{-9}	3.68×10^{-9}	2.52×10^{-9}	1.91×10^{-9}
W	7.59×10^{-8}	6.71×10^{-8}	5.01×10^{-8}	3.76×10^{-8}	2.94×10^{-8}	1.73×10^{-8}	8.10×10^{-9}	4.59×10^{-9}	3.16×10^{-9}	2.40×10^{-9}
WNW	6.15×10^{-8}	5.54×10^{-8}	4.23×10^{-8}	3.21×10^{-8}	2.52×10^{-8}	1.51×10^{-8}	7.15×10^{-9}	4.09×10^{-9}	2.83×10^{-9}	2.16×10^{-9}
NW	6.75×10^{-8}	6.27×10^{-8}	4.80×10^{-8}	3.67×10^{-8}	2.89×10^{-8}	1.75×10^{-8}	8.41×10^{-9}	4.84×10^{-9}	3.37×10^{-9}	2.58×10^{-9}
NNW	5.33×10^{-8}	4.56×10^{-8}	3.63×10^{-8}	2.84×10^{-8}	2.27×10^{-8}	1.42×10^{-8}	7.07×10^{-9}	4.16×10^{-9}	2.92×10^{-9}	2.26×10^{-9}

(a) 89-m effective release height (61-m stack height and 28-m plume rise).
(b) Data collected at the Hanford Meteorological Station from 1/76 through 1/84.

9 2 1 2 4 5 2 1 5 3 7

TABLE 4.1-6. 95th Percentile[a] Sector-Averaged $\bar{\chi}/Q'$ (s/m^3) Values, for Acute Ground-Level Releases from the 200 Areas[b]

	Range, mi (km)									
Direction	0.5 (0.8)	1.5 (2.4)	2.5 (4.0)	3.5 (5.6)	4.5 (7.2)	7.5 (12)	15 (24)	25 (40)	35 (56)	45 (72)
N	2.41×10^{-4}	3.64×10^{-5}	1.66×10^{-5}	1.02×10^{-5}	7.45×10^{-6}	3.86×10^{-6}	1.72×10^{-6}	9.88×10^{-7}	6.91×10^{-7}	5.27×10^{-7}
NNE	2.42×10^{-4}	3.65×10^{-5}	1.67×10^{-5}	1.02×10^{-5}	7.47×10^{-6}	3.87×10^{-6}	1.72×10^{-6}	9.90×10^{-7}	6.93×10^{-7}	5.28×10^{-7}
NE	2.25×10^{-4}	3.40×10^{-5}	1.55×10^{-5}	9.57×10^{-6}	6.96×10^{-6}	3.61×10^{-6}	1.61×10^{-6}	9.24×10^{-7}	6.46×10^{-7}	4.92×10^{-7}
ENE	2.00×10^{-4}	3.02×10^{-5}	1.38×10^{-5}	8.54×10^{-6}	6.19×10^{-6}	3.22×10^{-6}	1.43×10^{-6}	8.22×10^{-7}	5.75×10^{-7}	4.38×10^{-7}
E	2.01×10^{-4}	3.03×10^{-5}	1.39×10^{-5}	8.58×10^{-6}	6.22×10^{-6}	3.23×10^{-6}	1.44×10^{-6}	8.26×10^{-7}	5.77×10^{-7}	4.40×10^{-7}
ESE	1.65×10^{-4}	2.50×10^{-5}	1.15×10^{-5}	7.11×10^{-6}	5.16×10^{-6}	2.69×10^{-6}	1.20×10^{-6}	6.84×10^{-7}	4.80×10^{-7}	3.65×10^{-7}
SE	1.37×10^{-4}	2.10×10^{-5}	9.83×10^{-6}	5.91×10^{-6}	4.39×10^{-6}	2.26×10^{-6}	1.02×10^{-6}	5.76×10^{-7}	4.10×10^{-7}	3.10×10^{-7}
SSE	2.08×10^{-4}	3.14×10^{-5}	1.43×10^{-5}	8.87×10^{-6}	6.44×10^{-6}	3.35×10^{-6}	1.49×10^{-6}	8.54×10^{-7}	5.98×10^{-7}	4.55×10^{-7}
S	2.45×10^{-4}	3.70×10^{-5}	1.69×10^{-5}	1.04×10^{-5}	7.57×10^{-6}	3.92×10^{-6}	1.75×10^{-6}	1.00×10^{-7}	7.02×10^{-7}	5.35×10^{-7}
SSW	1.93×10^{-4}	2.91×10^{-5}	1.33×10^{-5}	8.26×10^{-6}	5.98×10^{-6}	3.11×10^{-6}	1.38×10^{-6}	7.94×10^{-7}	5.55×10^{-7}	4.23×10^{-7}
SW	2.17×10^{-4}	3.28×10^{-5}	1.50×10^{-5}	9.26×10^{-6}	6.73×10^{-6}	3.49×10^{-6}	1.55×10^{-6}	8.93×10^{-7}	6.24×10^{-7}	4.76×10^{-7}
WSW	2.22×10^{-4}	3.35×10^{-5}	1.53×10^{-5}	9.44×10^{-6}	6.87×10^{-6}	3.56×10^{-6}	1.59×10^{-6}	9.11×10^{-7}	6.37×10^{-7}	4.86×10^{-7}
W	2.92×10^{-4}	4.42×10^{-5}	2.01×10^{-5}	1.23×10^{-5}	9.02×10^{-6}	4.65×10^{-6}	2.07×10^{-6}	1.19×10^{-6}	8.35×10^{-7}	6.37×10^{-7}
WNW	3.09×10^{-4}	4.69×10^{-5}	2.13×10^{-5}	1.30×10^{-5}	9.55×10^{-6}	4.92×10^{-6}	2.20×10^{-6}	1.26×10^{-6}	8.85×10^{-7}	6.74×10^{-7}
NW	2.98×10^{-4}	4.51×10^{-5}	2.06×10^{-5}	1.26×10^{-5}	9.20×10^{-6}	4.74×10^{-6}	2.12×10^{-6}	1.22×10^{-6}	8.52×10^{-7}	6.50×10^{-7}
NNW	2.76×10^{-4}	4.18×10^{-5}	1.90×10^{-5}	1.17×10^{-5}	8.53×10^{-6}	4.40×10^{-6}	1.96×10^{-6}	1.13×10^{-6}	7.90×10^{-7}	6.02×10^{-7}

(a) One-hour average value with 5% probability of being exceeded.
(b) Based on data collected at the Hanford Meteorological Station during 1982 and 1983.

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TABLE 4.1-7. 95th Percentile[a] Sector-Averaged $\bar{\chi}/Q'$ (s/m^3) Values, for Acute Elevated Releases[b] from the 200 Areas

	Range, mi (km)									
Direction	0.5 (0.8)	1.5 (2.4)	2.5 (4.0)	3.5 (5.6)	4.5 (7.2)	7.5 (12)	15 (24)	25 (40)	35 (56)	45 (72)
N	2.28×10^{-5}	1.06×10^{-5}	6.32×10^{-6}	4.52×10^{-6}	3.47×10^{-6}	2.01×10^{-6}	9.80×10^{-7}	5.92×10^{-7}	4.23×10^{-7}	3.30×10^{-7}
NNE	1.85×10^{-5}	9.95×10^{-6}	5.96×10^{-6}	4.00×10^{-6}	2.94×10^{-6}	1.85×10^{-6}	9.70×10^{-7}	5.75×10^{-7}	4.08×10^{-7}	3.15×10^{-7}
NE	1.83×10^{-5}	9.93×10^{-6}	5.84×10^{-6}	3.83×10^{-6}	2.77×10^{-6}	1.74×10^{-6}	9.01×10^{-7}	5.36×10^{-7}	3.79×10^{-7}	2.93×10^{-7}
ENE	1.61×10^{-5}	9.53×10^{-6}	5.76×10^{-6}	3.71×10^{-6}	2.64×10^{-6}	1.74×10^{-6}	9.28×10^{-7}	5.49×10^{-7}	3.87×10^{-7}	2.99×10^{-7}
E	1.39×10^{-5}	8.98×10^{-6}	4.47×10^{-6}	3.34×10^{-6}	2.49×10^{-6}	1.48×10^{-6}	5.02×10^{-7}	3.54×10^{-7}	2.53×10^{-7}	2.11×10^{-7}
ESE	1.31×10^{-5}	9.18×10^{-6}	4.57×10^{-6}	3.35×10^{-6}	2.49×10^{-6}	1.38×10^{-6}	4.77×10^{-7}	2.95×10^{-7}	1.74×10^{-7}	1.40×10^{-7}
SE	1.25×10^{-5}	6.61×10^{-6}	2.77×10^{-6}	2.90×10^{-6}	2.41×10^{-6}	1.04×10^{-6}	4.21×10^{-7}	2.04×10^{-7}	1.33×10^{-7}	1.03×10^{-7}
SSE	1.85×10^{-5}	1.06×10^{-5}	5.98×10^{-6}	4.03×10^{-6}	2.97×10^{-6}	1.74×10^{-5}	8.65×10^{-7}	5.20×10^{-7}	3.68×10^{-7}	2.86×10^{-7}
S	2.92×10^{-5}	1.06×10^{-5}	6.07×10^{-6}	4.17×10^{-6}	3.11×10^{-6}	1.74×10^{-6}	7.67×10^{-7}	4.76×10^{-7}	3.37×10^{-7}	2.66×10^{-7}
SSW	3.02×10^{-5}	1.06×10^{-5}	6.07×10^{-6}	4.17×10^{-6}	3.11×10^{-6}	1.67×10^{-6}	5.01×10^{-7}	3.53×10^{-7}	2.44×10^{-7}	2.02×10^{-7}
SW	3.05×10^{-5}	1.06×10^{-5}	6.14×10^{-6}	4.26×10^{-6}	3.20×10^{-6}	1.78×10^{-6}	7.11×10^{-7}	4.50×10^{-7}	3.19×10^{-7}	2.54×10^{-7}
WSW	2.98×10^{-5}	1.06×10^{-5}	6.15×10^{-6}	4.28×10^{-6}	3.22×10^{-6}	1.78×10^{-8}	7.31×10^{-7}	4.59×10^{-7}	3.26×10^{-7}	2.58×10^{-7}
W	2.99×10^{-5}	1.06×10^{-5}	6.30×10^{-6}	4.50×10^{-6}	3.44×10^{-6}	1.98×10^{-6}	9.76×10^{-7}	5.86×10^{-7}	4.18×10^{-7}	3.25×10^{-7}
WNW	3.07×10^{-5}	1.06×10^{-5}	6.34×10^{-6}	4.56×10^{-6}	3.50×10^{-6}	2.02×10^{-6}	9.81×10^{-7}	5.94×10^{-7}	4.25×10^{-7}	3.31×10^{-7}
NW	2.87×10^{-5}	1.06×10^{-5}	6.24×10^{-6}	4.41×10^{-6}	3.36×10^{-6}	1.97×10^{-6}	9.88×10^{-7}	6.06×10^{-7}	4.37×10^{-7}	3.42×10^{-7}
NNW	2.14×10^{-5}	1.06×10^{-5}	6.30×10^{-6}	4.50×10^{-6}	3.44×10^{-6}	1.99×10^{-6}	9.77×10^{-7}	5.87×10^{-7}	4.19×10^{-7}	3.25×10^{-7}

(a) One-hour average value with 5% probability of being exceeded.
(b) Defined as 61 m.
(c) Based on data collected at the Hanford Meteorological Station during 1982 and 1983.

TABLE 4.1-8. 95th Percentile[a] Sector-Averaged $\bar{\chi}/Q'$ (s/m^3) Values, for Acute Ground-Level Releases from the 200 Areas[b]

	Range, mi (km)									
Direction	0.5 (0.8)	1.5 (2.4)	2.5 (4.0)	3.5 (5.6)	4.5 (7.2)	7.5 (12)	15 (24)	25 (40)	35 (56)	45 (72)
N	9.63×10^{-4}	1.61×10^{-4}	7.95×10^{-5}	5.00×10^{-5}	3.90×10^{-5}	2.27×10^{-5}	1.27×10^{-5}	8.74×10^{-6}	7.15×10^{-6}	6.03×10^{-6}
NNE	9.88×10^{-4}	1.65×10^{-4}	8.12×10^{-5}	5.12×10^{-5}	3.99×10^{-5}	2.33×10^{-5}	1.30×10^{-5}	8.95×10^{-6}	7.30×10^{-6}	6.16×10^{-6}
NE	1.03×10^{-3}	1.71×10^{-4}	8.41×10^{-5}	5.32×10^{-5}	4.14×10^{-5}	2.41×10^{-5}	1.35×10^{-5}	9.29×10^{-6}	7.56×10^{-6}	6.39×10^{-6}
ENE	8.91×10^{-4}	1.50×10^{-4}	7.46×10^{-5}	4.66×10^{-5}	3.65×10^{-5}	2.13×10^{-5}	1.19×10^{-5}	8.16×10^{-6}	6.70×10^{-6}	5.64×10^{-6}
E	9.68×10^{-4}	1.62×10^{-4}	7.99×10^{-5}	5.02×10^{-5}	3.92×10^{-5}	2.29×10^{-5}	1.28×10^{-5}	8.79×10^{-6}	7.18×10^{-6}	6.06×10^{-6}
ESE	6.88×10^{-4}	1.16×10^{-4}	5.79×10^{-5}	3.60×10^{-5}	2.83×10^{-5}	1.65×10^{-5}	9.24×10^{-6}	6.32×10^{-6}	5.19×10^{-6}	4.37×10^{-6}
SE	4.70×10^{-4}	7.59×10^{-5}	3.71×10^{-5}	2.42×10^{-5}	1.84×10^{-5}	1.09×10^{-5}	6.01×10^{-6}	4.17×10^{-6}	3.37×10^{-6}	2.85×10^{-6}
SSE	8.70×10^{-4}	1.47×10^{-4}	7.32×10^{-5}	4.56×10^{-5}	3.58×10^{-5}	2.09×10^{-5}	1.17×10^{-5}	7.99×10^{-6}	6.57×10^{-6}	5.25×10^{-6}
S	9.33×10^{-4}	1.56×10^{-4}	7.75×10^{-5}	4.85×10^{-5}	3.80×10^{-5}	2.21×10^{-5}	1.24×10^{-5}	8.50×10^{-6}	6.96×10^{-6}	5.86×10^{-6}
SSW	7.06×10^{-4}	1.18×10^{-4}	5.82×10^{-5}	3.68×10^{-5}	2.86×10^{-5}	1.67×10^{-5}	9.33×10^{-6}	6.41×10^{-6}	5.24×10^{-6}	4.42×10^{-6}
SW	7.55×10^{-4}	1.26×10^{-4}	6.27×10^{-5}	3.94×10^{-5}	3.07×10^{-5}	1.80×10^{-5}	1.00×10^{-5}	6.89×10^{-6}	5.64×10^{-6}	4.75×10^{-6}
WSW	7.66×10^{-4}	1.28×10^{-4}	6.36×10^{-5}	4.00×10^{-5}	3.12×10^{-5}	1.82×10^{-5}	1.02×10^{-5}	6.99×10^{-6}	5.73×10^{-6}	4.82×10^{-6}
W	1.18×10^{-3}	1.93×10^{-4}	9.41×10^{-5}	6.01×10^{-5}	4.65×10^{-5}	2.71×10^{-5}	1.51×10^{-5}	1.05×10^{-5}	8.47×10^{-3}	7.18×10^{-6}
WNW	1.23×10^{-3}	2.01×10^{-4}	9.78×10^{-5}	6.28×10^{-5}	4.84×10^{-5}	2.82×10^{-5}	1.57×10^{-5}	1.09×10^{-5}	8.81×10^{-6}	7.48×10^{-6}
NW	1.22×10^{-3}	2.00×10^{-4}	9.73×10^{-5}	6.23×10^{-5}	4.81×10^{-5}	2.80×10^{-5}	1.56×10^{-5}	1.09×10^{-5}	8.76×10^{-6}	7.44×10^{-6}
NNW	1.04×10^{-3}	1.73×10^{-4}	8.50×10^{-5}	5.38×10^{-5}	4.18×10^{-5}	2.44×10^{-5}	1.36×10^{-5}	9.40×10^{-6}	7.65×10^{-6}	6.47×10^{-6}

(a) One-hour average value with 5% probability of being exceeded.
(b) Data collected at the Hanford Meteorological Station from 1/76 through 1/84.

9 2 1 2 4 6 2 1 5 4 0

TABLE 4.1-9. 95th Percentile[(a)] Sector-Averaged $\bar{\chi}/Q'$ (s/m^3) Values, for Acute Elevated Releases[(b)] from the 200 Areas[(c)]

Direction	Range, mi (km) 0.5 (0.8)	1.5 (2.4)	2.5 (4.0)	3.5 (5.6)	4.5 (7.2)	7.5 (12)	15 (24)	25 (40)	35 (56)	45 (72)
N	4.10×10^{-5}	2.58×10^{-5}	1.92×10^{-5}	1.48×10^{-5}	1.22×10^{-5}	9.43×10^{-6}	5.74×10^{-6}	4.77×10^{-6}	3.93×10^{-6}	3.60×10^{-6}
NNE	3.66×10^{-5}	2.44×10^{-5}	1.58×10^{-5}	1.38×10^{-5}	1.21×10^{-5}	8.49×10^{-6}	5.29×10^{-6}	4.45×10^{-6}	3.65×10^{-6}	3.37×10^{-6}
NE	3.47×10^{-5}	2.39×10^{-5}	1.47×10^{-5}	1.29×10^{-5}	1.17×10^{-5}	7.68×10^{-6}	5.09×10^{-6}	4.09×10^{-6}	3.34×10^{-6}	3.03×10^{-6}
ENE	3.12×10^{-5}	2.36×10^{-5}	1.38×10^{-5}	1.30×10^{-5}	1.19×10^{-5}	7.78×10^{-6}	4.91×10^{-6}	3.77×10^{-6}	3.07×10^{-6}	2.73×10^{-6}
E	2.81×10^{-5}	1.80×10^{-5}	1.26×10^{-5}	1.09×10^{-5}	9.28×10^{-6}	6.17×10^{-6}	4.32×10^{-6}	3.08×10^{-6}	2.50×10^{-6}	2.15×10^{-6}
ESE	2.85×10^{-5}	1.84×10^{-5}	1.26×10^{-5}	1.01×10^{-5}	8.08×10^{-6}	5.12×10^{-6}	2.78×10^{-6}	2.04×10^{-6}	1.68×10^{-6}	1.46×10^{-6}
SE	2.15×10^{-5}	1.07×10^{-5}	1.17×10^{-5}	7.95×10^{-6}	5.82×10^{-6}	3.50×10^{-6}	1.89×10^{-6}	1.52×10^{-6}	1.25×10^{-6}	1.14×10^{-6}
SSE	3.99×10^{-5}	2.45×10^{-5}	1.60×10^{-5}	1.29×10^{-5}	1.18×10^{-5}	7.55×10^{-6}	4.89×10^{-6}	3.74×10^{-6}	3.05×10^{-6}	2.70×10^{-6}
S	4.42×10^{-5}	2.48×10^{-5}	1.69×10^{-5}	1.29×10^{-5}	1.16×10^{-5}	7.18×10^{-6}	4.65×10^{-6}	3.30×10^{-6}	2.68×10^{-6}	2.29×10^{-6}
SSW	4.52×10^{-5}	2.48×10^{-5}	1.69×10^{-5}	1.24×10^{-5}	1.05×10^{-5}	6.16×10^{-6}	3.83×10^{-6}	2.75×10^{-6}	2.24×10^{-6}	1.93×10^{-6}
SW	4.56×10^{-5}	2.51×10^{-5}	1.75×10^{-5}	1.33×10^{-5}	1.12×10^{-5}	6.98×10^{-6}	4.35×10^{-6}	3.10×10^{-6}	2.52×10^{-6}	2.16×10^{-6}
WSW	4.47×10^{-5}	2.52×10^{-5}	1.76×10^{-5}	1.32×10^{-5}	1.14×10^{-5}	7.05×10^{-6}	4.48×10^{-6}	3.19×10^{-6}	2.59×10^{-6}	2.22×10^{-6}
W	4.54×10^{-5}	2.58×10^{-5}	1.90×10^{-5}	1.46×10^{-5}	1.22×10^{-5}	9.11×10^{-6}	5.40×10^{-6}	4.63×10^{-6}	3.81×10^{-6}	3.53×10^{-6}
WNW	4.62×10^{-5}	2.59×10^{-5}	1.94×10^{-5}	1.49×10^{-5}	1.22×10^{-5}	9.54×10^{-6}	5.93×10^{-6}	4.85×10^{-6}	4.00×10^{-6}	3.64×10^{-6}
NW	4.48×10^{-5}	2.55×10^{-5}	1.85×10^{-5}	1.45×10^{-5}	1.22×10^{-5}	1.02×10^{-5}	6.98×10^{-6}	5.28×10^{-6}	4.37×10^{-6}	3.84×10^{-6}
NNW	4.27×10^{-5}	2.58×10^{-5}	1.90×10^{-5}	1.47×10^{-5}	1.22×10^{-5}	9.15×10^{-6}	5.69×10^{-5}	4.74×10^{-6}	3.94×10^{-6}	3.59×10^{-6}

(a) One-hour average value with 5% probability of being exceeded.
(b) Defined as 61 m.
(c) Based on data collected at the Hanford Meteorological Station during 1982 and 1983.

4.1.8 300 Area

The wind rose for the 300 Area (Station 11) shows that the largest (and approximately the same) percentage of wind blow from the northwest/north-northwest and south-southwest/southwest directions (Figure 4.1-2); however, the winds from the southwest quadrant tend to be stronger.

Data collected by Washington Public Power Supply System for WNP-1 and data collected from the 10-m towers at the 300 and 400 Areas have been significantly different. Because these locations are relatively close together, PNL constructed 60-m towers in the 300 and 400 Areas in 1986 to provide additional wind and temperature information to further define meteorological conditions in this area.

Data from these towers are being collected and will be available in 1989.

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4.2 GEOLOGY AND HYDROLOGY

4.2.1 Geology and Physiography

The Hanford Site is located in the Pacific Northwest in a semiarid region of southeastern Washington State. This portion of the state lies within the Columbia Plateau and is defined generally by a thick accumulation of basaltic lava flows that extend laterally from central Washington eastward into Idaho and southward into Oregon (Tallman et al. 1979). Deformation of these lava flows has formed a number of broad structural and topographic basins. The Hanford Site lies within the Pasco Basin near the confluence of the Yakima and Columbia rivers.

The Hanford Site overlies the structural low point of the Pasco Basin. The boundaries of the Pasco Basin are defined by anticlinal structures of basaltic rock. These structures are the Saddle Mountains to the north; the Umtanum Ridge, Yakima Ridge, and Rattlesnake Hills to the west; and the Rattlesnake Hills and a series of doubly plunging anticlines merging with the Horse Heaven Hills to the south. The terrain within the Pasco Basin is relatively flat. Its surface features were formed by catastrophic floods and have undergone little modification since with the exception of more recently formed sand dunes (DOE 1986b).

Within the Pasco Basin, the basaltic lava flows of the Columbia River Basalt Group are covered by late Miocene to Pleistocene-age fluvial, lacustrine, and glaciofluvial sediments. During the late Miocene to mid-Pliocene, intercalated fluvial and lacustrine sediments, known as the Ringold Formation, partially filled the subsiding Pasco Basin (Myers et al. 1979). Pleistocene-age glaciofluvial sediments, informally known as the Hanford formation, overlie the Ringold Formation. The deposition of these coarser materials was a result of catastrophic postglacial flood events.

The terrain of the central and eastern parts of the Hanford Site is relatively flat (DOE 1986b). The northern and western parts of the Site have moderate to steep topographic ridges composed of basalt and sediments. The central part of the Site, including the 200-Area Plateau, has undergone minimal erosion since formation by floodwaters about 13,000 years ago.

The elevations of the alluvial plain that covers much of the Hanford Site vary from 105 m above mean sea level in the southeast corner to 245 m in the northwest. The 200-Area Plateau in the central part of the Hanford Site varies in elevation from 190 to 245 m. The highest point is on Rattlesnake Mountain (1,093 m) at the southwestern border of the Hanford Site.

The major geologic units of the Hanford Site are in ascending order: basement rocks of unknown origin and composition, the Columbia River Basalt Group with interbedded sediments of the Ellensburg Formation, the Ringold Formation, the Plio-Pleistocene unit, and the Hanford formation. Locally, Pleistocene/Holocene sand, silt, and loess exist as surficial material.

The regional geology is dominated by the thick sequence of tholeiitic flood basalts designated the Columbia River Basalt Group. This layered sequence consists of more than 200,000 km^3 of basalt covering more than 155,000 km^2 and is subdivided into five formations (Ledgerwood et al. 1978; Swanson et al. 1979). The upper three formations, the Grande Ronde Basalt, the Wanapum Basalt, and the Saddle Mountains Basalt collectively constitute the Yakima Basalt Subgroup (Swanson et al. 1979). Approximately 100 basalt flows, including both Columbia River basalts and older lavas, have been identified from geophysical logs obtained from a 3,250 m deep borehole (RSH-1) located just west of the Hanford Site (Swanson et al. 1979). Flows of the Columbia River Basalt Group are interbedded with and overlain by Miocene-Pliocene epiclastic and volcaniclastic sediments of the Ellensburg Formation (Myers et al. 1979). These sedimentary interbeds become thicker and more frequent in the Saddle Mountains Formation.

Continued deformation following the cessation of Columbia River Basalt volcanism resulted in the further accumulation of sediments in the Pasco Basin. These sediments of the Ringold Formation were deposited between 3.7 and about 8.5 million years before present (mybp) in a fluvial/flood plain environment (Myers et al. 1979) and accumulated to a thickness of over 365 m.

An eolian silt and fine sand (the Plio-Pleistocene unit) overlies the Ringold Formation in the western part of the Hanford Site (Brown 1960). This silty fine sand to sandy silt was deposited when the wind reworked and redeposited Ringold sediments. Relatively high caliche contents are found in much of this unit.

The Hanford formation lies on the eroded surface of the Plio-Pleistocene unit the Ringold Formation, or locally, on the basalt bedrock. The Hanford formation consists of catastrophic flood sediments that were deposited when ice dams in western Montana and northern Idaho were breached and massive volumes of water spilled abruptly across eastern and central Washington. The floods scoured the land surface, locally eroding the Ringold Formation and the basalts and sedimentary interbeds, leaving a network of buried channels crossing the Pasco Basin (Tallman et al. 1979). Thick sequences of sediments were deposited by several episodes of Pleistocene flooding with the last major flood sequence dated at about 13,000 years before present (Myers et al. 1979). These sediments have locally been divided into two main facies, termed the "Pasco Gravels" facies and the "Touchet Beds" facies (Myers et al. 1979).

Eolian sediments consisting of loess and sand dunes (both active and inactive) locally veneer the surface of the Hanford Site.

Most known faults within the region are associated with anticlinal fold axes (i.e., thrust or reverse faults, although normal faults do exist) and were probably formed concurrently with the folding (DOE 1986b). Existing known faults within the Hanford area include tear faults with lengths of up to 3 km (1.9 mi) on Gable Mountain and the Rattlesnake-Wallula alignnment, which has been interpreted as a right-lateral strike-slip fault. The faults in central Gable Mountain are considered capable by NRC criteria (10 CFR 100, Appendix A) in that they have slightly displaced the Hanford formation gravels, but their relatively short lengths give them low seismic potential. Also, there is no observed seismicity on or near Gable Mountain. The Rattlesnake-Wallula alignment is interpreted as possibly being capable, in part because of lack of any distinct evidence to the contrary and because this structure continues along the northwest trend of faults that appear active at Wallula Gap, some 56 km (35 mi) southeast of the Hanford Site (DOE 1986b).

Strike-slip faults have not been observed cross cutting the Pasco Basin. Anticlinal ridges that bound the Pasco Basin have been mapped in detail, and except for some component of dextral movement on the Rattlesnake-Wallula alignment, no strike-slip faults similar to those in the western Yakima Fold Belt have been observed (DOE 1986b). Tear faults have been observed along the ridges at boundaries between geometrically coherent segments of the structures, as in the Saddle Mountains, but these faults are confined to the individual structures and formed as different geometries developed in the fold. Similar-type faults have been mapped on Gable Mountain and studied in detail. These features are also interpreted as tear faults that are a response to folding.

In general, it has been found that for structures within the Hanford Site the greatest deformation occurs in the hinge area of the anticlinal ridges and decreases with distance from that area, that is, the greatest amount of tectonic jointing and faulting occurs in the hinge zone and decreases toward the gently dipping limbs. The faults usually exhibit low dips with small displacements, may be confined to the layer in which they occur, and die out to no recognizable displacement in short lateral distances (DOE 1986b).

4.2.2 Soils

Hajek (1966) lists and describes 15 different soil types on the Hanford Site. These are listed and briefly described in Table 4.2-1, and shown in Figure 4.2-1.

4.2.3 Seismicity

Earthquake records for the Pacific Northwest extend back to about 1850. The early records are very qualitative and were documented mainly from reports of tremors that were felt. In 1969 a network of siesmographs was installed on the Columbia Plateau and earthquakes occurring within the central Columbia Plateau have been located instrumentally since that date. The distribution and intensity of historical earthquakes indicate that the Columbia Plateau is an area of moderate seismicity (Figure 4.2-2). Seismic activity above magnitude 3.0 on the Richter scale has occurred in this region, but activity above magnitude 3.5 is most commonly found around the

TABLE 4.2-1. Soil Types on the Hanford Site (after Hajek 1966)

Name and (symbol)	Description
Ritzville Silt Loam (Ri)	Dark colored silt loam soils midway up the slopes of the Rattlesnake Hills. Developed under bunch grass from silty wind-laid deposits mixed with small amounts of volcanic ash. Characteristically >60 in. deep, but bedrock may occur at <60 in. but >30 in.
Rupert Sand (Rp)	One of the most extensive soils on the Hanford Site. Brown-to-grayish brown coarse sand grading to dark grayish brown at about 36 in. Developed under grass, sagebrush, and hopsage in coarse sandy alluvial deposits that were mantled by wind-blown sand. Hummocky teraces and dune-like ridges.
Hezel Sand (He)	Similar to Ruper sands; however, a laminated grayish brown strongly calcareous silt loam subsoil is usually encountered within 40 in. of the surface. Surface soil is very dark brown and was formed in wind-blown sands that mantled lake-laid sediments.
Koehler Sand (Kf)	Similar to other sandy soils on the Hanford Site. Developed in a wind-blown sand mantle. Differs from other sands in that the sand mantles a lime-silica cemented layer "hardpan." Very dark grayish brown surface layer is somewhat darker than Rupert. Calcareous subsoil is usually dark grayish brown at about 18 in.
Burbank Loamy Sand (Ba)	Dark-colored, coarse-textured soil underlain by gravel. Surface soil is usually about 16 in. thick but can be 30 in. thick. Gravel content of subsoil ranges from 20 to 80%.
Kiona Silt Loam (Ki)	Occupies steep slopes and ridges. Surface soil is very dark grayish brown and about 4 in. thick. Dark brown subsoil contains basalt fragments 12 in. and larger in diameter. Many basalt fragments found in surface layer. Basalt rock outcrops present. A shallow stony soil normally occurring in association with Ritzville and Warden soils.

TABLE 4.2-1. (contd)

Name and (symbol)	Description
Warden Silt Loam (Wa)	Dark grayish brown soil with a surface layer usually 9 in. thick. Silt loam subsoil becomes strongly calcareous at about 20 in. and becomes lighter colored. Granitic boulders are found in many areas. Usually >60 in. deep.
Ephrata Sandy Loam (El)	Surface is dark colored and subsoil is dark grayish brown medium-textured soil underlain by gravelly material, which may continue for many feet. Level topography.
Ephrata Stony Loam (Eb)	Similar to Ephrata sandy loam. Differs in that many large mummocky ridges are presently made up of debris released from melting glaciers. Areas between hummocks contain many boulders several feet in diameter.
Scootney Stoney Silt Loam (Sc)	Developed along the north slope of Rattlesnake Hills, usually confined to floors of narrow draws or small fan-shape areas where draws open onto plains. Severely eroded with numerous basaltic boulders and fragments exposed. Surface soil is usually dark grayish brown grading to grayish brown in the subsoil.
Pasco Silt Loam (P)	Poorly drained very dark grayish brown soil formed in recent alluvial material. Subsoil is variable, consisting of stratified layers. Only small areas found on Hanford Site located in low areas adjacent to the Columbia River.
Esquatzel Silt Loam (Qu)	Deep dark brown soil formed in recent alluvium derived from loess and lake sediments. Subsoil grades to dark grayish brown in many areas but color and texture of the subsoil is variable due to the stratified nature of the alluvial deposits.
Riverwash (Rv)	Wet, periodically flooded areas of sand, gravel, and boulder deposits which make up overflowed islands in the Columbia river and adjacent land.

TABLE 4.2-1. (contd)

Name and (symbol)	Description
Dune Sand (D)	Miscellaneous land type that consists of hills or ridges of sand-sized particles drifted and piled up by wind and are either actively shifting or so recently fixed or stabilized that no soil horizons have developed.
Lickskillet Silt Loam (Ls)	Occupies ridge slopes of Rattlesnake Hills and slopes >2,500 ft. elevation. Similar to Kiona series except surface soils are darker. Shallow over basalt bedrock, with numerous basalt fragments throughout the profile.

Further information can be found in Hajeck (1966).

northern and western portions of the Columbia Plateau, with a few events occurring along the border between Washington and Oregon (DOE 1986b).

Swarms of small, shallow earthquakes are the predominant seismic events of the Columbia Plateau (DOE 1986a). Earthquake swarms, as detected by the regional seismograph network, may contain from four to more than (DOE 1986b). The earthquake swarms characteristically do not follow a typical mainshock-aftershock sequence; earthquakes within the swarms generally increase and decay in frequency but not in magnitude.

Shallow earthquake swarm activity in the central Columbia Plateau is concentrated principally north and east of the Hanford Site. Here earthquakes of magnitude greater than 3.0 also occur. The swarm event of perhaps the largest magnitude was recorded instrumentally on December 20, 1973, as a magnitude 4.4 earthquake located in the Royal Slope area, north of the Hanford Site (DOE 1986b).

Deeper earthquakes (to a depth of 28 km) occur in the central Columbia Plateau, although at much lower frequencies than the shallower swarm events. The 28-km depth is the approximate thickness of the earth's crust beneath this portion of Washington State (Caggiano and Duncan 1983). Deep seismic activity generally occurs randomly and is not associated with known geologic structures or with patterns of shallow seismicity (DOE 1986b).

9 2 1 2 4 6 2 1 5 5 2

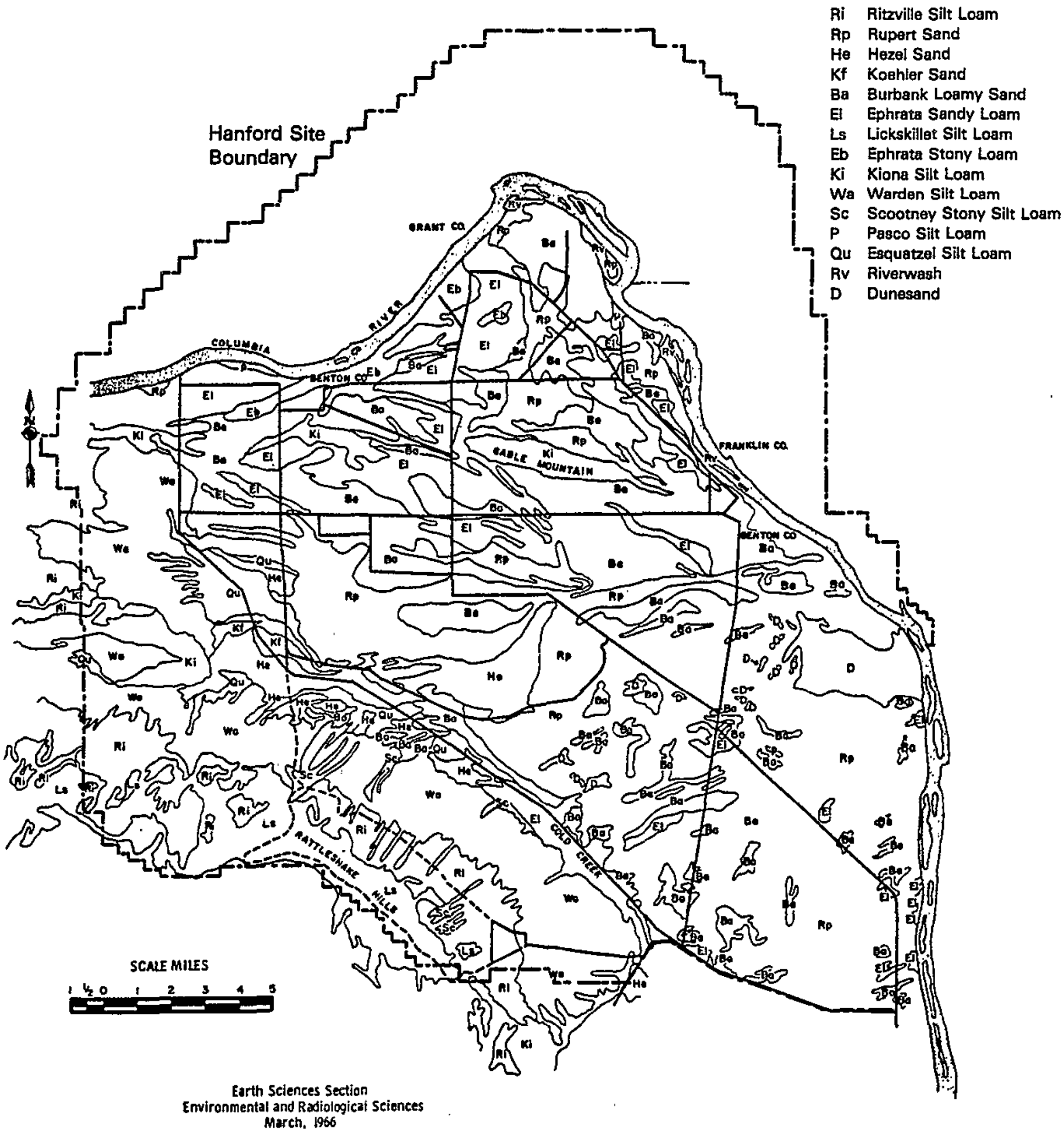

FIGURE 4.2-1. Soil Types of the Hanford Reservation

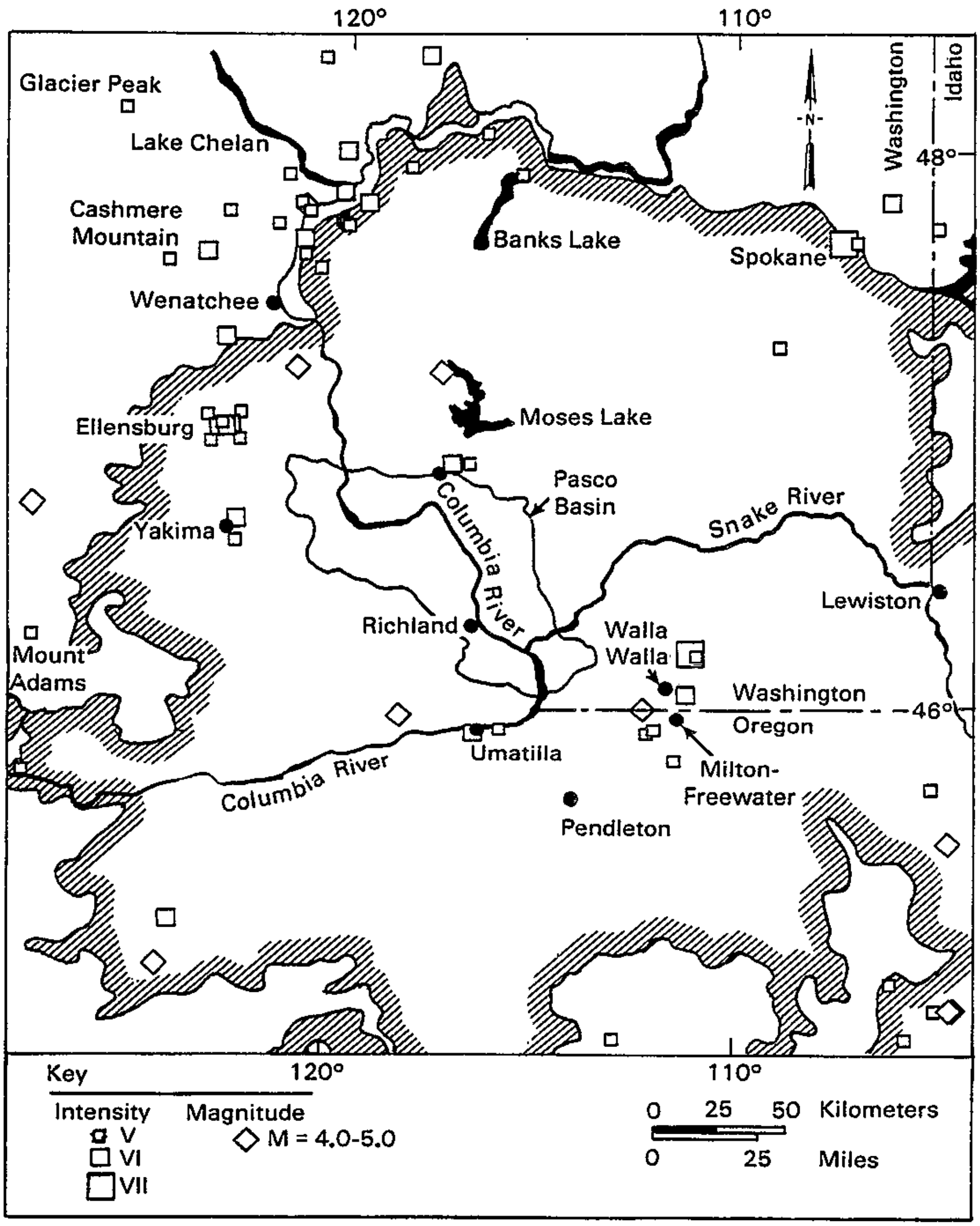

FIGURE 4.2-2. Historical Seismicity of the Columbia Plateau. All earthquakes between 1850 and 1969 with modified Mercalli intensity equal to or greater than V are shown (DOE 1986b).

4.2.4 Hydrology

Surface Water

The Hanford Site occupies approximately 33% of the land area within the Pasco Basin. Primary surface-water features associated with the Hanford Site are the Columbia and Yakima rivers. Several surface ponds and ditches are present and are generally associated with fuel and waste processing activities (Figure 4.3-6 in the Ecology Section).

Flow from approximately 66% of the Hanford Site drains directly into the Columbia River along the Hanford reach, which extends from the headwaters of Lake Wallula to the Priest Rapids Dam. The Columbia River flow has been inventoried and is described in detail by the U.S. Army Corps of Engineers (DOE 1986b). Flow along this reach is controlled by the Priest Rapids Dam. Several drains and intakes are also present along this reach, including irrigation outfalls from the Columbia Basin Irrigation Project and Hanford Site intakes for the onsite water export system.

Cold Creek and its tributary, Dry Creek, are ephemeral streams within the Yakima River drainage system along the southern boundary of the Hanford Site. Both streams drain areas to the west of the Hanford Site and cross the southwestern part of the Hanford Site toward the Yakima River. Surface flow, when it occurs, infiltrates and disappears into the surface sediments in the western part of the Hanford Site. Rattlesnake Springs located on the western part of the Hanford Site forms a small surface stream that flows for about 3 km before disappearing into the ground. Approximately 33% of the Hanford Site is drained by the Yakima River system.

The Yakima River, bordering the southern portion of the Hanford Site, has a lower annual flow than the Columbia River. For a recorded period of 57 years, the average annual flow of the Yakima River is about 104 m^3/s with monthly maximum and minimum flows of 490 m^3/s and 4.6 m^3/s, respectively. Recorded flow rates of the Columbia River have ranged from 4,500 to 18,000 m^3/s during the runoff in spring and early summer, to 1,000 to 4,500 m^3/s during the low flow period of late summer and winter (Jamison 1982). The average annual Columbia River flow in the Hanford reach, based on 65 years of record, is about 3,400 m^3/s (DOE 1986a). Normal river elevations within the Hanford Site range from 120 m above mean sea level where the river enters the Hanford Site near Vernita to 104 m where it leaves the Hanford Site near the 300 Area.

Ground Water

Ground water under the Hanford Site occurs in unconfined and confined conditions. The unconfined aquifer is contained within the glaciofluvial sands and gravels and within the Ringold Formation. It is found predominantly in the middle member of the Ringold Formation, which consists of sorted sands and gravels of varying hardness. The bottom of the aquifer is the basalt surface or, in some areas, the clay zones of the lower member of the Ringold Formation. The confined aquifers consist of sedimentary interbeds and/or interflow zones that occur between dense basalt flows in the Columbia River Basalt Group. The main waterbearing portions of the interflow zones occur within a network of interconnecting vesicles and fractures of the flow tops or flow bottoms.

Sources of natural recharge to the unconfined aquifer are rainfall and runoff from the higher bordering elevations, water infiltrating from small ephemeral streams, and river water along influent reaches of the Yakima and Columbia rivers. The movement of precipitation through the unsaturated (vadose) zone has been studied at several locations on the Hanford Site to define the movement of water in the vadose zone. Conclusions from these studies are varied depending on the location studied. Some investigators conclude that no downward percolation of precipitation occurs on the 200-Area Plateau where soil texture is varied and layered with depth and that all moisture penetrating the soil is removed by evaporation. Others have observed downward water movement below the root zone in tests conducted near the 300 Area where soils are coarse textured and precipitation was above normal (DOE 1986a).

From the recharge areas to the west, the ground water flows downgradient to the discharge areas, primarily along the Columbia River. This general west-to-east flow pattern is interrupted locally by the ground-water mounds in the 200 Areas. From the 200 Areas, there is also a component of ground-water flow to the north between Gable Mountain and Gable Butte. These flow directions represent current conditions; the aquifer is dynamic and responds to changes in natural and artificial recharge.

Local recharge to the shallow basalts is believed to result from infiltration of precipitation and runoff along the margins of the Pasco Basin. Regional recharge of the deep basalts is thought to result from interbasin ground-water movement originating northeast and northwest of the Pasco Basin in areas where the Wanapum and Grande Ronde Basalts crop out extensively (DOE 1986b). Ground-water discharge from the shallow basalt is probably to the overlying unconfined aquifer and the Columbia River. The discharge area(s) for the deep ground waters is currently uncertain, but flow is believed to be generally southeastward with discharge speculated to be south of the Hanford Site (DOE 1986b).

4.2.5 Flooding

Large Columbia River floods have occurred in the past (DOE 1986a), but the likelihood of recurrence of large-scale flooding has been reduced by the construction of several flood control/water storage dams upstream of the Hanford Site. Major floods on the Columbia River are typically the result of rapid melting of the winter snowpack over a wide area augmented by above-normal precipitation. The maximum historical flood on record occurred June 7, 1894, with a peak discharge at the Hanford Site of 21,000 m^3/s. The flood plain associated with the 1894 flood is shown in Figure 4.2-3. The largest recent flood took place in 1948 with an observed peak discharge of 20,000 m^3/s at the Hanford Site. The probability of flooding at the magnitude of the 1894 and 1948 floods has been greatly lowered because of upstream regulation by dams (Figure 4.2-4).

There have been fewer than 20 major floods on the Yakima River since 1862 (DOE 1986b). The most severe occurred in November 1906, December 1933, and May 1948. Discharge magnitudes at Kiona, Washington, were 1,870, 1,900, and 1,050 m^3/s, respectively. The recurrence intervals for the 1933 and 1948 floods are estimated at 170 and 33 years, respectively. The development of irrigation reservoirs within the Yakima River Basin has considerably reduced the flood potential of the river. Lands susceptible to a 100-year flood on the Yakima River are shown in Figure 4.2-5. Flooded areas could extend into the southern section of the Hanford Site, but the Yakima River upstream is

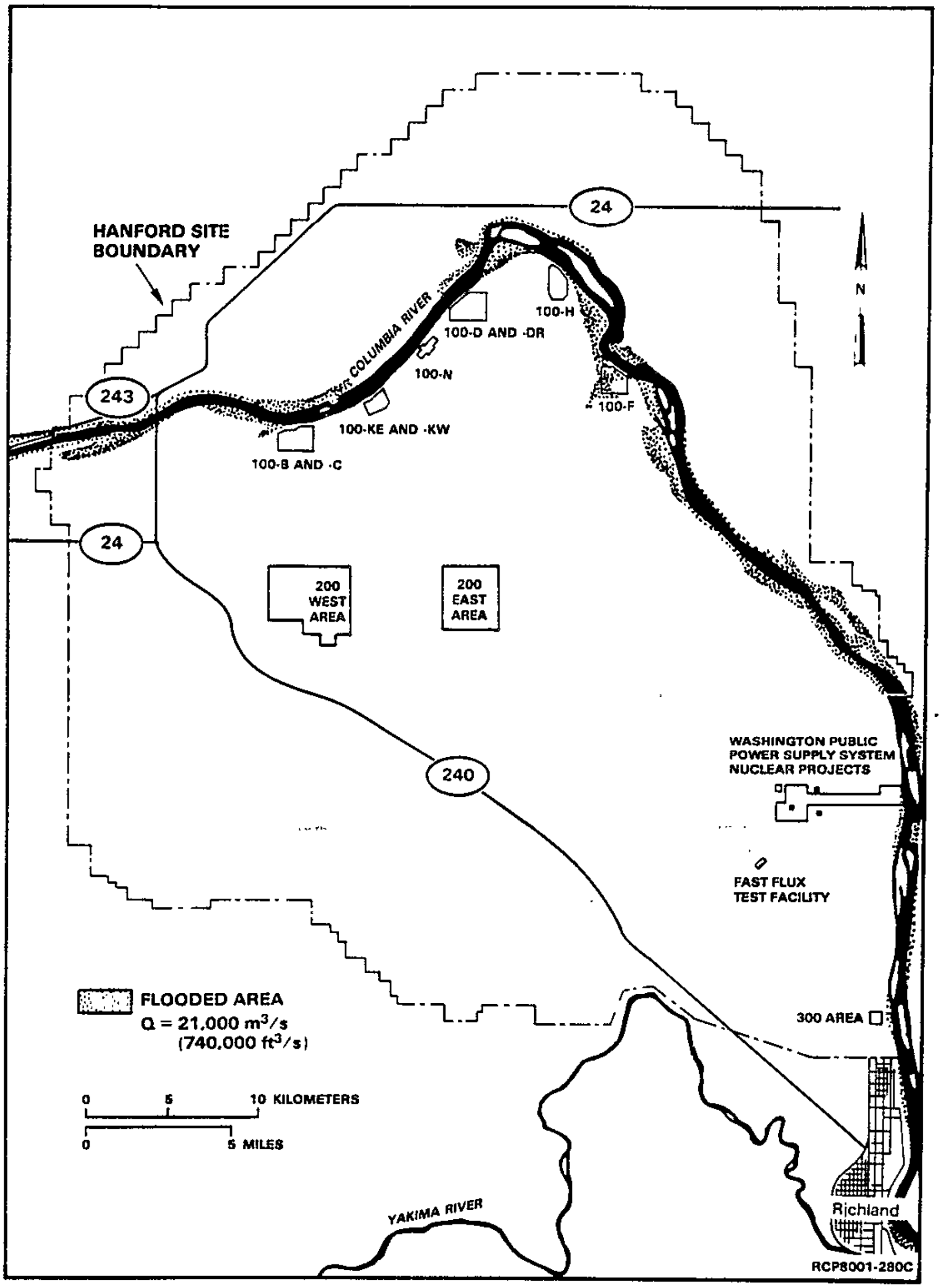

FIGURE 4.2-3. Flood Area During the 1894 Flood (DOE 1986b)

9 2 1 2 4 6 2 1 5 5 7

9 2 1 2 4 5 2 1 5 5 8

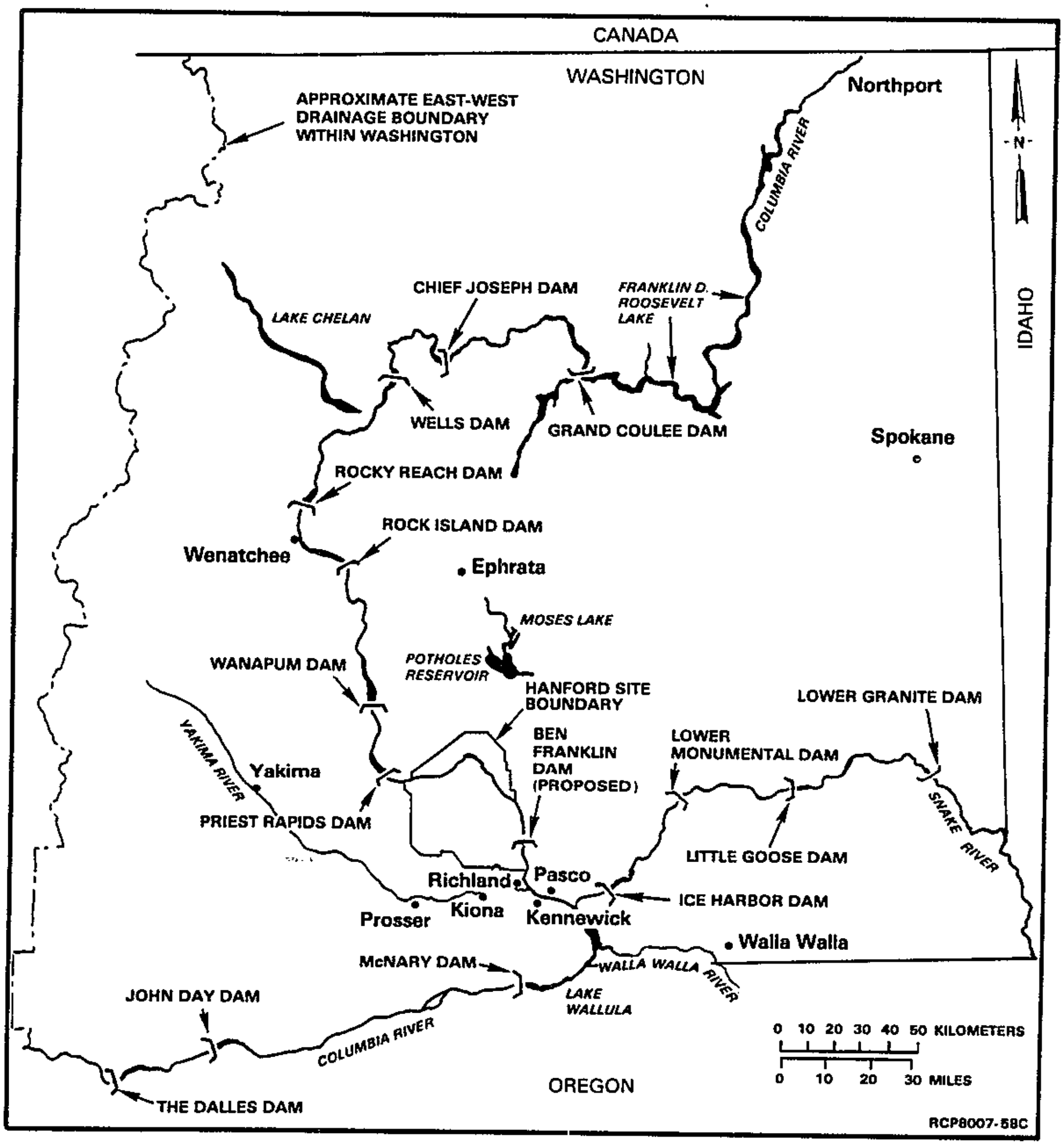

FIGURE 4.2-4. Locations of Principal Dams Within the Columbia Plateau Study Area (DOE 1986b)

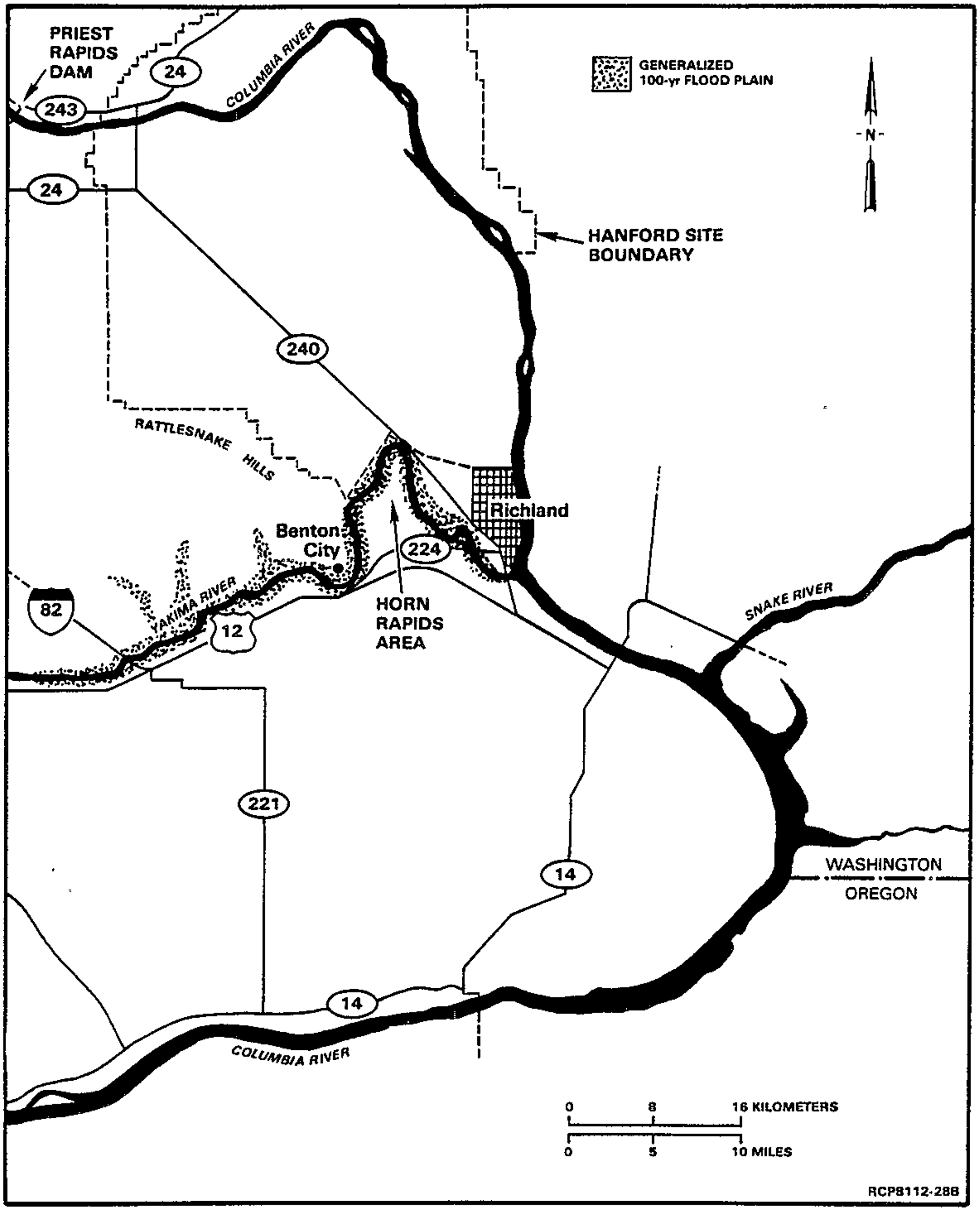

FIGURE 4.2-5. Flood Area from a 100-Year Flood of the Yakima River in the Vicinity of the Hanford Site (DOE 1986b)

physically separated from the Hanford Site by the Rattlesnake Hills, which would prevent major flooding of the Hanford Site.

Evaluation of flood potential is conducted in part through the concept of the probable maximum flood, which is determined from the upper limit of precipitation falling on a drainage area and other hydrologic factors, such as antecedent moisture conditions, snowmelt, and tributary conditions. The probable maximum flood for the Columbia River below Priest Rapids Dam has been calculated to be 40,000 m^3/s. The flood plain associated with the probable maximum flood is shown in Figure 4.2-6. This flood would inundate the 100 Areas located adjacent to the Columbia River, but the central portion of the Hanford Site would remain unaffected (DOE 1986b).

Potential dam failures on the Columbia River have been evaluated, and upstream failures could arise from a number of causes. The magnitude of the resulting flood will depend on the degree of breaching at the dam. The U.S. Army Corps of Engineers evaluated a number of scenarios on the effects of failures of Grand Coulee Dam, assuming flow conditions on the order of 11,000 m^3/s. The discharge resulting from a 50% breach at the outfall of Grand Coulee Dam was determined to be 600,000 m^3/s. In addition to the areas inundated by the probable maximum flood, the remainder of the 100 Areas, the 300 Area, and nearly all of Richland, Washington, would be flooded (DOE 1986b). No determinations were made for breaches greater than 50% of Grand Coulee, for failures of dams upstream, or for associated failures downstream of Grand Coulee. The 50% scenario was believed to represent the largest realistically conceivable flow resulting from a natural or human-induced breach (DOE 1986b).

The possibility of a landslide resulting in river blockage and flooding along the Columbia River has also been examined for an area bordering the east side of the river upstream from the city of Richland. The possible landslide area considered was the 75-m high bluff generally known as White Bluffs. Calculations were made for an 8×10^5-m^3 landslide volume with a concurrent flood flow of 17,000 m^3/s (a 200-year flood) resulting in a flood wave crest elevation of 122 m above mean sea level. Areas inundated upstream from such a landslide event would be similar to those shown in Figure 4.2-6 (DOE 1986b).

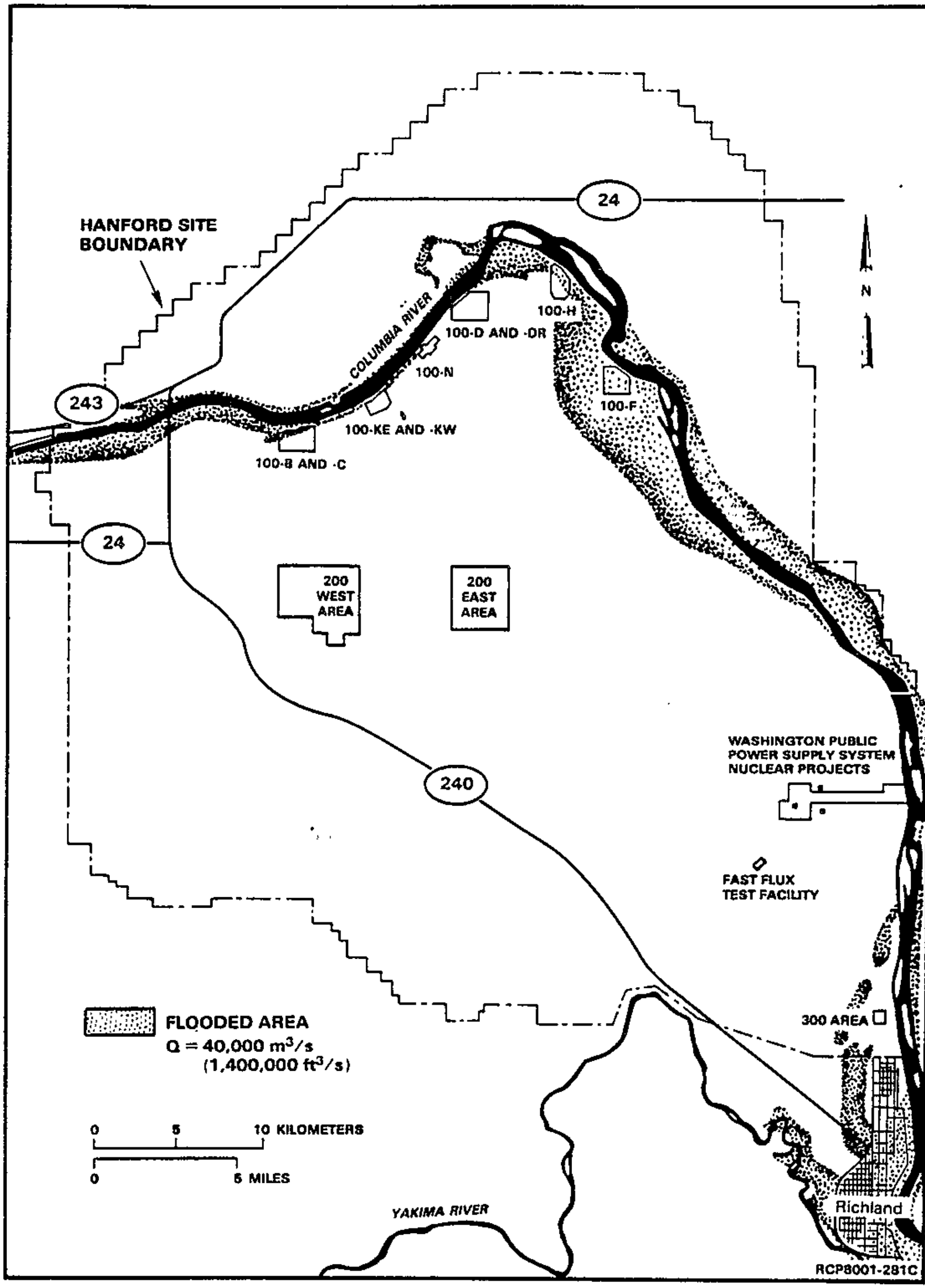

FIGURE 4.2-6. Flood Area for the Probable Maximum Flood (DOE 1986b)

9 2 1 2 4 5 2 1 5 5 1

4.2.6 Water Quality

Columbia River

The Washington State Department of Ecology classifies the Columbia River as Class A (excellent) between Grand Coulee Dam and the mouth of the river near Astoria, Oregon (DOE 1986b). The Class A designation requires that industrial uses of this water be compatible with other uses, including drinking water, wildlife, and recreation (PNL 1987). The Hanford reach of the Columbia River is the last free-flowing portion of the river in the United States, although flow is regulated by Priest Rapids Dam immediately upstream from the Hanford Site.

Pacific Northwest Laboratory (PNL) conducts routine monitoring of the Columbia River for both radiological and nonradiological water-quality parameters. A yearly summary of results has been published since 1973 (PNL 1987). Numerous other water-quality studies have been conducted on the Columbia River relative to the impact of the Hanford Site over the past 37 years. The U.S. Department of Energy (DOE) currently holds a National Pollutant Discharge Elimination System (NPDES) permit for eight effluent discharges into the Columbia River.

Radiological monitoring shows low levels of radionuclides in samples of Columbia River water. Hydrogen-3 (tritium), iodine-129, and uranium are found in slightly higher concentrations downstream of the Hanford Site than upstream (PNL 1988), but were well below concentration guidelines established by the U.S. Department of Energy and the U.S. Environmental Protection Agency drinking water standards. Cobalt-60 and iodine-131 were not consistently found in measurable quantities during 1987 in samples of Columbia River water from Priest Rapids Dam, the 300-Area water intake, or the Richland city pumphouse (PNL 1988). The average annual strontium-90 concentrations were essentially the same at Priest Rapids Dam and the Richland Pumphouse for 1987, and were well below the State of Washington and EPA drinking water standards (PNL 1988).

Unconfined Aquifer

Water quality data for the unconfined aquifer in the Pasco Basin were obtained from the U.S. Geological Survey (USGS) (Graham et al. 1981). These data are from samples collected from wells outside the Hanford Site. Chemical analyses are available for well samples collected at Hanford between the years 1974 and 1949 by the USGS. These analyses are reported in PNL documents (e.g., PNL 1987).

The ground-water composition is that of a dilute (less than or approximately 350 mg/L total dissolved solids) calcium-bicarbonate chemical type. Other principal chemical constituents include sulfate, silica, magnesium, and nitrate (the latter contributed through the disposal of chemical reprocessing waters).

Contamination of the ground water results from releases from various liquid-waste disposal facilities. Nitrate, tritium, and total beta contamination have migrated away from these sites in a general west-to-east direction. Some longer-lived radionuclides such as strontium-90 and cesium-137 have reached the ground water, primarily through liquid-waste disposal cribs. Small quantities of longer-lived radionuclides have reached the water table via a failed ground-water monitoring well casing and through reverse well injection, a disposal practice which was discontinued at Hanford in 1947 (Smith 1980). The occurrence and consequences of leaks from waste storage tanks and the occurrence of radioactive materials in soils have been described elsewhere (ERDA 1975). These occurrences have not resulted, and are not expected to result, in radiation exposure to the public (ERDA 1975; DOE 1986a).

Springs are common on basalt ridges surrounding the Pasco Basin. Geochemically, spring waters are of a calcium-sodium-bicarbonate type with low dissolved solids (approximately 200 to 400 mg/L) (DOE 1986b). Compositionally, these waters are similar to shallow local ground waters (unconfined aquifer and upper Saddle Mountains Basalt). However, they are readily distinguishable from waters of the lower Saddle Mountains (Mabton interbed) and the Wanapum and Grande Ronde basalts, which are of sodium-bicarbonate to sodium-chloride-bicarbonate (or sodium-chloride-sulfate) type. Currently, there is no evidence suggesting that these spring waters contain any significant component of deeper ground water.

Confined Aquifers

Areal and stratigraphic changes in ground-water chemistry characterize basalt ground waters beneath the Hanford Site (Graham et al. 1981). The stratigraphic position of these changes is believed to delineate flow-system boundaries and to identify chemical evolution taking place along ground-water flow paths. Some potential mixing of ground waters has also been located using these data. The rate of mixing is currently unknown.

Overall, waters of the shallow basalts are of a sodium-bicarbonate chemical type; those of the deep basalts are of a sodium-chloride chemical type (DOE 1986b). On a location-by-location basis, chemical and isotopic shifts can be pronounced (DOE 1982). The stratigraphic boundaries separating chemical types vary depending on location. At the Reference Repository Location, ground-water composition was found to change systematically as a function of depth (DOE 1986b).

Iodine-129 and tritium have been detected in confined ground-water zones in the Saddle Mountains Basalt beneath the Hanford Site (DOE 1986b). Two areas have above-background concentrations of iodine-129. These areas are in the vicinity of West Lake and Gable Mountain Pond and at one borehole located approximately 20 km to the southeast near the horn of the Yakima River.

4.2.7 Environmental Monitoring

The DOE has conducted an environmental monitoring program at the Hanford Site for the past 42 years. The monitoring results have been recorded since 1946 in quarterly reports. Since 1958, the results have been available as annual reports (recently summarized by Soldat et al. 1986). For calendar year 1986, the monitoring results for offsite and onsite environs, and for onsite ground water are combined in one PNL report (PNL 1987).

Radioactive materials in air were sampled continuously on the Hanford Site, at the Hanford Site perimeter, and in nearby and distant communities in the Columbia Basin at a total of 48 locations. No sample collected at the Hanford Site perimeter or in surrounding communities exceeds 0.17% of the applicable DOE Derived Concentration Guides (PNL 1987).

Ground water was collected from 339 wells in 1986 that sample both the confined and unconfined aquifers beneath the Hanford Site. The major plume of tritium-contaminated ground water continued to move eastward, resulting in seepage into the Columbia River. Samples of Columbia River water were collected immediately upstream and downstream from the Hanford Site. Concentrations of all radionuclides observed in river water were all well below applicable EPA and state of Washington drinking-water standards (PNL 1987).

Foodstuffs from the area, including those irrigated with Columbia River water, were sampled. All results were similar to the low concentrations found in foodstuffs grown in other adjacent areas, indicating no measurable impact as a result of Hanford operations.

Deer, rabbits, game birds, waterfowl, and fish were also collected and analyzed. Game birds, waterfowl, fish, and deer showed low levels of cesium-137 attributable to Hanford operations. Other concentrations of radionuclides were typical of levels attributable to worldwide weapon-test fallout.

Low concentrations of radionuclides were measured in onsite and offsite samples of soil and vegetation during 1986. The levels were similar to those obtained in previous years and no discernible increase in the concentration could be attributed to current Hanford operations. Dose rates from external penetrating radiation measured in the vicinity of local residential areas were similar to those observed in previous years, and no contribution from Hanford activities could be identified.

Nonradiological monitoring was conducted for chemical constituents of ground-water samples from 90 wells located throughout the Hanford Site. Elevated levels (above detection levels) of cadmium, chromium, nitrate, and total organic carbon were found in samples in the 100 Areas compared with samples from other areas of the Hanford Site. The same constituents, plus copper and zinc were most frequently detected for the 200 Areas. Monitoring for hazardous materials indicated low concentrations of many of the constituents, which would be expected in natural ground water. All of the water quality parameters for the Hanford reach of the Columbia River were within state of Washington water quality standards for Class A waters (PNL 1988).

Measured and calculated radiation doses to the general public from Hanford operations were well below applicable regulatory limits throughout

1986. The calculated 50-year cumulative whole-body dose received by a hypothetical maximally exposed individual was about 2 millirem during 1986. This is a decrease of 1 millirem over the value reported for 1985. The calculated 50-year whole-body dose to the population living within 80 km of the Hanford Site was about 8 person-rem, as compared with 7 person-rem in 1985.

These doses are much less than doses potentially received by the general public from other common sources of radiation (see Figure 4.2-7). They can also be compared to the approximately 100 millirem and 34,000 person-rem received annually by an average individual and surrounding population, respectively, as a result of naturally occurring radiation. The calculated effective dose equivalent using the new DOE Radiation Standards for the Protection of the Public was 0.09 millirem for 1986, compared with the new limits of 100 millirem per year for prolonged exposure and 500 millirem per year for occasional annual exposure to a maximally exposed individual (PNL 1987).

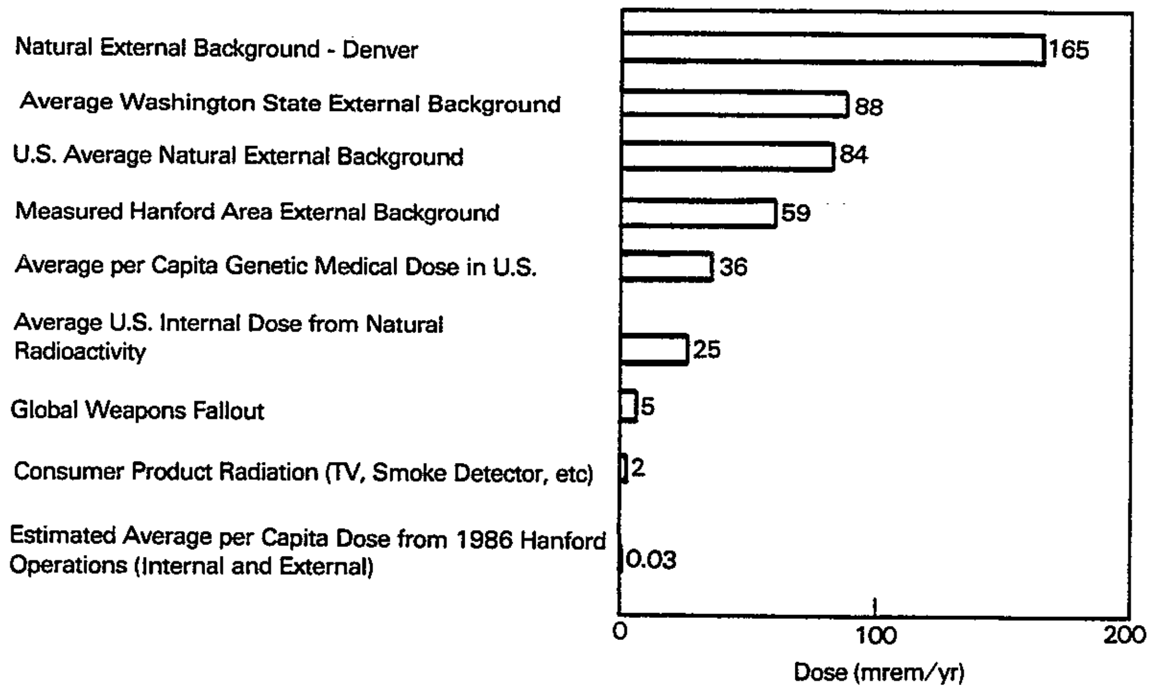

FIGURE 4.2-7. Annual Radiation Doses from Various Sources (PNL 1987)

4.2.8 100 Areas

The geologic units beneath the 100 Areas can be divided into three distinct units: the Columbia River Basalt Group, the Ringold Formation, and the glaciofluvial sediments (see Figure 4.2-8). The Columbia River Basalt Group is a compact, dense, and hard lava and forms the bedrock in the 100 Areas. The surface of the basalt generally reflects the structure of the basalt series and is only locally modified by erosion (Brown 1962).

In the western part of the 100 Areas, near the 100-B and 100-K Areas, the upper approximately 30 m of basalt are essentially continuous without significant interbeds. To the east, near 100-H and 100-F Areas, there are numerous interbeds within the upper portion of the basalts. The interbed materials are predominantly sand, gravel, clay, and volcanic ash. Some of these interbeds may correlate with the Pliocene-age Ellensburg Formation of central Washington. Drill cuttings from some wells have shown that the upper surface of the basalt may be vesicular to scoriaceous, which is caused by the escape of gases during cooling of the basalt lava. Samples from greater than about 3 m below the surface of the basalt are generally hard, dense, fine textured, and dark gray.

Overlying the basalt bedrock are the clays, silts, sands, and gravels of the Ringold Formation. Over much of the Hanford Site various members of the the Ringold Formation are distinguishable, but within the 100 Areas the various members are not as clearly distinct from each other and are not readily differentiated. Generally in the northwestern part of the Hanford Site, the Ringold Formation is dominantly coarse material such as sands and gravels, farther to the east it grades into sand and coarse silt, and on the eastern margin it is mostly silt and clay. The upper portion of the Ringold Formation is probably absent beneath most of the reactor areas because of erosion, but within the 100 Areas the Ringold Formation is up to about 185 m in thickness (Brown 1962).

Extensive portions of the middle part of the Ringold Formation contain sand and gravels thoroughly cemented with calcium carbonate, making them highly resistant to erosion. One of the most pronounced areas is in the Columbia River channel near the 100-K Area.

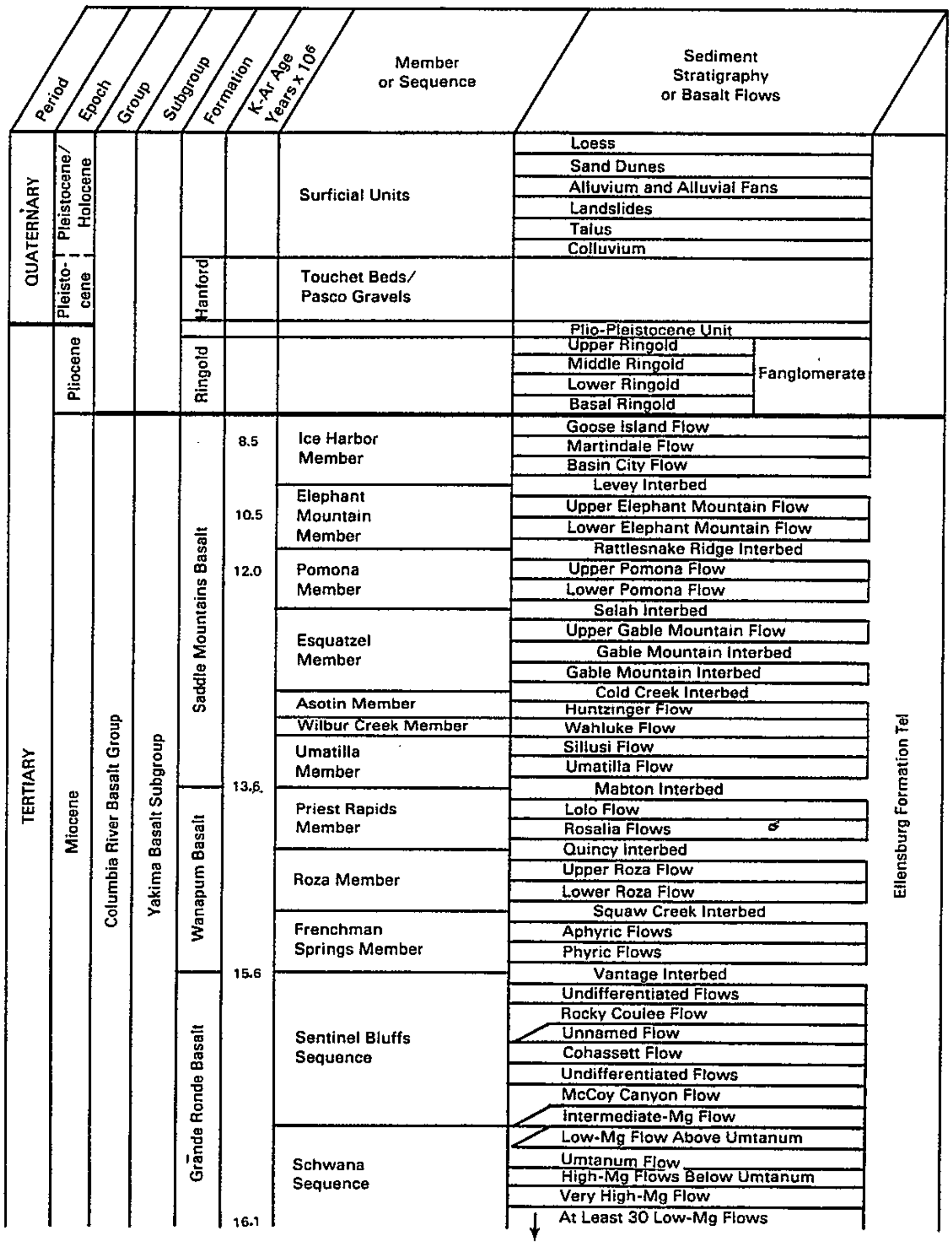

FIGURE 4.2-8. Stratigraphic Units Present in the Pasco Basin

Glaciofluvial sediments consisting of sand, gravel, and boulders with occasional lenses of fine, well-sorted materials overlie the eroded Ringold Formation surface in the 100 Areas. Areas of hummocky topography, believed to be associated with the disintegrating ice mass to the north and with melting icebergs, are found in the 100-K and 100-D Areas. There are also areas where wind has reworked the finer outwash material and formed sand dunes and well-sorted beds of sandy silt. The glaciofluvial materials are up to about 50 m in thickness in the 100 Areas.

The water table, representing the upper boundary of the unconfined ground water, varies in depth beneath the 100 Areas from 10 m or less to about 30 m, with an average depth of about 20 m (McGhan et al. 1985). Recharge is generally from the highland areas to the south and southwest, and flow is in general toward the Columbia River.

The vertical permeability of the basalt flows is relatively low particularly when compared to the horizontal permeability of the interflow zones. The ground water within the basalt series is quite separate and distinct from that in the post-basalt sediments. The Ringold Formation material directly overlying the basalt is of relatively low permeability while the glaciofluvial material overlying the Ringold Formation may have permeabilities several orders of magnitude higher.

Tracer tests have shown that the ground water moves at relatively high velocities through glaciofluvial sediments deposited in eroded channels in the Ringold Formation surface. Several of these channels are known to occur in the 100 Areas. One of the most prominent is located just north of Gable Mountain.

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4.2.9 200 Areas

The 200 Areas (Separations Areas) near the center of the Hanford Site are located on a broad flood bar. This bar is commonly referred to as the 200-Area Plateau.

The major geologic units beneath the 200 Areas are, in ascending order; basement rocks of undetermined origin, the Columbia River Basalt Group with intercalated sediments of the Ellensburg Formation, the Ringold Formation, the Plio-Pleistocene unit, and the Hanford formation (see Figure 4.2-8). The surface of the 200 Areas is veneered with loess and sand dunes of varying thickness.

The Columbia River Basalt Group is a thick sequence of tholeiitic flood basalts. This layered sequence is subdivided into five formations (Ledgerwood et al. 1978; Swanson et al. 1979). The upper three formations, the Grande Ronde Basalt, the Wanapum Basalt, and the Saddle Mountains Basalt collectively, constitute the Yakima Basalt Subgroup (Swanson et al. 1979). Beneath the 200 Areas, this basalt sequence is at least 1,460 m thick and may be as much as 4267 m thick (Myers et al. 1979). Flows of the Columbia River Basalt Group are interbedded with and overlain by Miocene-Pliocene epiclastic and volcaniclastic sediments of the Ellensburg Formation (Myers et al. 1979).

The Ringold Formation is present throughout most of the 200 Areas and has been divided into four textural units: 1) sand and gravel of the basal Ringold member; 2) clay, silt, and fine sand with minor gravel lenses of the lower Ringold member; 3) occasionally cemented sand and gravel of the middle Ringold member; and 4) silt and fine sand of the upper Ringold member (Brown 1959).

The silts and sands of the lower Ringold member were deposited in the still forming synclinal depressions. This low energy fluvial/lacustrine deposit is thickest in the Cold Creek syncline. The unit pinches out on the flanks of the Umtanum-Gable Mountain Structure where it apparently was not deposited.

The middle silty sandy gravel member is the thickest Ringold member beneath the Separations Areas. In general, the upper part of the middle Ringold unit is not indurated except for isolated cementation from calcium carbonate, while the lower part of the unit is moderately to well indurated.

The upper Ringold member is present only beneath parts of the 200-West Area. This silty sand member contains several caliche horizons indicating that the eroded surface of the unit was exposed to subarial processes of a semiarid to arid environment comparable to that of the present day. The upper Ringold member apparently was completely stripped by erosional processes throughout the remainder of the Separations Areas.

The Plio-Pleistocene unit, an eolian silt and fine sand, overlies the Ringold Formation in the western part of the Hanford Site (Brown 1960). Normal fluvial processes as well as Pleistocene catastrophic flooding apparently stripped much of the eolian deposit within the Separations Areas (Tallman et al. 1979).

The Hanford formation lies on the eroded surface of the Plio-Pleistocene unit, the Ringold Formation, and locally the basalt bedrock. The Hanford formation has locally been divided into two main facies, termed the "Pasco Gravels" facies and the "Touchet Beds" facies (Myers et al. 1979).

The Pasco Gravels facies (Tallman et al. 1979) is composed of poorly sorted, subrounded to angular clasts that commonly display foreset bedding (Myers et al. 1979). These sediments indicate high-energy depositional environments. The Touchet Beds facies consists of rhythmically bedded sequences of graded silt, sand, and minor gravel units. These deposits are limited to areas where slack-water conditions occurred during the impoundment of flood waters behind the Wallula Gap constriction (Tallman et al. 1979; Myers et al. 1979).

Eolian sediments consisting of both active and inactive sand dunes locally veneer the surface of the 200 Areas.

Depth to ground water in the 200-East Area is about 75 m and in 200-West Area about 50-60 m. Recharge to the 200 Areas, which is essentially in the center of the Hanford Site, is described under Regional Hydrology above.

Ground-water flow direction is generally in an easterly and southeasterly direction toward the Columbia River.

Hydrogeology Beneath the 200-West Area. The hydrogeologic units of principal interest are, in ascending order: the Pomona member, a thick and dense basalt flow(s) that forms the base of the Rattlesnake Ridge aquifer; the Rattlesnake Ridge interbed that forms the physical framework of the uppermost basalt aquifer; the Elephant Mountain member that forms the confining bed over the Rattlesnake Ridge aquifer; the Ringold Formation that forms the framework of the locally confined basal Ringold aquifer and the unconfined aquifer; and the Plio-Pleistocene unit and Hanford formation that form the framework of the unsaturated (vadose) zone.

The Pomona member averages about 45 m thick beneath the 200-West Area, and thins to the northwest (Myers et al. 1979). Northeast of Gable Mountain the Pomona displays for intraflow structures are a basal colonnade and entablature, an upper colonnade, and a flow top (Fecht 1978). The interior of the Pomona is dense and exhibits very low permeability. Hydraulic conductivity of the Columbia River basalt flow interiors is extremely low, ranging from 10^{-6} to 10^{-8} m/day. However, flow tops of the Saddle Mountains Basalt typically have higher equivalent hydraulic conductivities ranging from 10^{2} to 10^{-2} m/day.

The Rattlesnake Ridge interbed was deposited on the weathered surface of the Pomona. Its thickness averages about 27 m. Locally it has been divided into four facies on the basis of composition. These facies are in ascending order: 1) a clayey basalt conglomerate formed by the weathering and reworking of the Pomona flow top, 2) an epiclastic fluvial-floodplain unit deposited by the ancestral Columbia River system, 3) a tuff made up of an air fall ash and 4) a tuffite derived from fluvial reworking of the tuff and epiclastic detritus (Graham et al. 1984). The tuff and tuffite units exhibit higher natural radioactivity (as indicated by natural gamma logs) and high glass content in borehole samples. These units remain relatively constant in grain size but vary in thickness. Grain size ranges from sandy gravel to sands and silts, which appear to interfinger and grade laterally into one another.

The Rattlesnake Ridge interbed forms the uppermost, regionally extensive confined aquifer. The different lithologies produce some degree of anisotropy and heterogeneity within the aquifer.

The Elephant Mountain Member (10.5 mybp) is the uppermost and youngest basalt member beneath the 200-West Area. It is generally conformable to the surface of the Rattlesnake Ridge interbed but in areas has been found to be invasive into the underlying sediments (Fecht 1978). The member consists of two flows or flow lobes. Only the lowermost flow (Elephant Mountain I) is present, averaging about 87 m in thickness. Fecht (1978) describes three intraflow structures in the lower flow. These are in ascending order: colonnade, entablature, and flow top. The interior of the Elephant Mountain I flow is dense with very low hydraulic conductivities typical of the Columbia River basalts. This low hydraulic conductivity acts to confine the Rattlesnake Ridge aquifer (Graham et al. 1984).

The Ringold Formation is present and continuous beneath the 200-West Area. Its thickness averages 120 m (Tallman et al. 1979), thickening to the southwest. All four textural units (basal lower, middle, and upper) are present; only the upper Ringold is discontinuous.

The basal Ringold unit, the oldest and lowermost, directly overlies and is conformable to the Elephant Mountain Member. It averages about 15 m thick and thickens as it dips to the southwest. The basal Ringold is predominately a matrix-(sand-) supported gravel unit with stringers of coarse-to-fine sand and silt. Beneath the 200-West Area, where the basal Ringold is capped by the lower Ringold, it forms a confined aquifer.

The lower Ringold unit occurs throughout the Hanford Site and averages approximately 15 m thick. The surface of the unit dips to the southwest where it also thickens. The texture of this unit ranges from a silty coarse-to-medium sand to sandy silt, generally becoming finer from north to south. Stringers of coarse-to-fine pebbles, up to 1 ft thick, are common. Also, fine pebbles are found scattered throughout beds within the unit. The lower Ringold unit has hydraulic conductivities of 1 to 1.36 m/day (Graham 1981) and serves to confine the basal Ringold aquifer.

The silty sandy gravel of the middle Ringold unit is also present throughout the 200-West Area. This unit is the major constituent of the Ringold Formation averaging about 90 m thick, thinning to the north and east. The unit consists of well-rounded pebbles and small cobbles with a matrix of coarse-to-fine sand and silt. The amount of cementation varies but generally is greatest in the lower part of the unit where it is moderately indurated with calcium carbonate and/or silica. Silt and sand lenses up to 5 m thick are present within the conglomerate.

The sand, silt, and clay of the upper Ringold unit are present but discontinuous beneath the 200-West Area. Where present, its thickness averages about 6 m. The unit is composed of well-sorted sand and silt with minor lenses of fine pebbles. A caliche horizon often caps the upper Ringold. Other caliche horizons have been identified throughout the unit.

The Plio-Pleistocene unit lies unconformably on the upper and middle Ringold members beneath nearly all of the 200-West Area. This unit, which resulted from the reworking and redeposition of the upper Ringold member sediment by wind, averages about 6 m in thickness. The sediments are typically fine grained consisting predominantly of very fine sand and silt. A relatively high calcium carbonate content is present in the eolian silts, suggesting that the deposit contains reworked caliche from the upper Ringold member (Tallman et al. 1979).

The major surface and near-surface sand and gravel deposits in the 200-West Area are the glaciofluvial sediments of the Hanford formation. The Hanford formation averages about 45 m in thickness and is composed of the Pasco gravel facies. Beneath the 200-West Area these sediments can be further broken down into three main units based on texture. The lowermost unit is a slightly silty medium-to-very-fine sand. It is present only in the southern half of the Hanford Site and becomes finer to the south. The middle unit, a pebbly coarse-to-medium sand to slightly silty coarse-to-medium sand, is present throughout the 200-West Area, except for areas to the north and west. The unit averages about 25 m thick and generally grades from coarse sediments in the northwest to finer sediments in the south and west. The uppermost textural unit of the Hanford formation in the 200-West Area is a silty sandy gravel to slightly silty very-coarse-to-coarse sand. This unit forms the surficial materials of the 200-West Area, except in the extreme south where it is not present, or where local deposits of loess occur. As with the other Hanford units these sediments also appear to become finer to the south.

Hydrogeology of the 200-East Area. Areas north and east of the 200-East Area (Gable Mountain Pond and B Pond) are incorporated into this description. The geologic units of principal interest are the same in the 200-East Area as they are in the 200-West Area. There are, however, some notable differences in the occurrence of specific units and in the thickness and extent of those units.

The Pomona Member, which forms the base of the Rattlesnake Ridge aquifer, averages about 56 m thick beneath this portion of the Hanford Site and thickens slightly to the south. On the western Gable Mountain anticline it is typified by four major intraflow structures: basal colonnade, entablature, upper colonnade, and flow top (Fecht 1978). The interior of the Pomona Member is dense and exhibits very low permeability.

The Rattlesnake Ridge interbed beneath the 200-East Area is equivalent to the unit under the 200-West Area as described above. This unit is the uppermost, regionally extensive confined aquifer in the area. As beneath the 200-West Area, the varying lithologies produce some degree of anisotropy and heterogeneity affecting the flow of ground water.

The Elephant Mountain Member (10.5 mybp) is the uppermost and youngest basalt member beneath this area and is generally conformable to the surface of the Rattlesnake Ridge interbed. In some areas the Elephant Mountain Member has been found to be invasive into the underlying sediments (Fecht 1978). The basalt member consists of two flows or flow lobes. The lowermost flow (Elephant Mountain I) is continuous over most of this area, ranging in thickness from 35 m to 11.5 m (where it is partially eroded away) and thinning to about 6 m over Gable Mountain. Fecht (1978) describes three intraflow structures in the lower flow. These are in ascending order: colonnade, entablature, and flow top. The upper flow (Elephant Mountain II) is present only in the southeast and northern portions of the area. This flow is roughly one-quarter the thickness of the Elephant Mountain I flow (averaging

7.7 m) and thickening to the southeast and north. An interflow zone separates the two flows. This interflow zone has interconnecting vesicles and rubbly zones.

The Elephant Mountain Member forms the bedrock surface beneath the area, except where it has been locally eroded, exposing the older units. Much of this erosion occurred during the deposition of Ringold sediments, as the ancestral Columbia River flowed through the structural low west of Gable Mountain (Graham et al. 1984). Further erosion occurred following deposition of the Ringold Formation, as Pleistocene catastrophic floods inundated the area. Both the Elephant Mountain I and II flows are dense, low permeability, basalt flows with very low hydraulic conductivities typical of the Columbia River basalts.

The Ringold Formation is present beneath the Hanford Site, except at Gable Mountain where the formation was apparently not deposited, and in the area north of the 200-East Area, where main stream currents of late Pleistocene flooding have completely removed it (Graham et al. 1984). The Ringold Formation averages approximately 60 m thick beneath the 200-East Area, 40 m thick beneath B Pond, and is absent beneath Gable Mountain Pond. All four textural units, basal, lower, middle, and upper have been identified.

The basal Ringold unit directly overlies the Elephant Mountain Member. In the southern portion of the 200-East Area it is overlain by the lower Ringold unit and is well defined. In the central portion of the area, the lower Ringold unit apparently pinches out, making definition of the basal Ringold difficult due to its similarities to the now overlying middle Ringold unit (Graham et al. 1984). The basal Ringold averages about 22 m thick and thickens to the south.

The lower Ringold unit ranges from silty coarse-to-medium sand, to a sandy silt to clay (Tallman et al. 1979) and locally includes some gravel stringers. The lower Ringold unit sediments are generally compacted and exhibit a variety of degrees of induration.

The middle Ringold unit occurs throughout the 200-East Area except over Gable Mountain and in the deeply eroded channels adjacent to Gable Mountain.

Its thickness averages approximately 30 m in the southern part of the area, thinning toward the north and east. Erosion has modified the surface of the middle Ringold unit. Reworked portions are often difficult to differentiate from the undisturbed portions. The unit consists of well-rounded pebble-to-cobble-size gravel with a matrix of sand, silt, and some clay. Induration of the unit ranges from virtually no cement to well cemented by calcium carbonate and/or silica. Consolidation of the unit ranges from matrix-supported conglomerate to open-work uncemented gravel (Tallman et al. 1979).

The upper Ringold unit is identified only near B Pond and consists of a fine to very fine sand averaging about 3 m thick. The unit was likely not deposited on Gable Mountain, and elsewhere it has been eroded away.

Surface and near-surface deposits are of unconsolidated sand and gravel of the Hanford formation. The thickness of the Hanford formation averages about 60 m but thins to approximately 10 m beneath Gable Mountain Pond. The Hanford formation can be broken down into three main textural units beneath the 200-East Area.

The lowermost unit is a pebbly very coarse sand to sandy gravel that is relatively thin (approximately 10 m) and lies directly on the middle Ringold unit. This unit is present mostly beneath the southern and eastern portions of the area possibly extending to beneath B Pond.

The middle textural unit is a coarse-to-fine sand unit. This unit is the thickest and most extensive Hanford formation unit in the vicinity. It averages about 60 m thick and is present throughout the 200-East Area, except in the northeastern portion where a main channel appears to cut through the unit (Tallman et al. 1979). The unit has a wide variation of grain size, ranging from pebbly very coarse-to-medium sand to a slightly silty medium-to-fine sand.

The uppermost unit is a fairly thin silty sandy gravel and occurs only in the northwestern portion of the 200-East Area.

Hydrology. The unconfined aquifer beneath the Hanford Site is contained within the Ringold Formation and the overlying Hanford formation. The unconfined aquifer is affected by disposal of waste water to surface and subsurface disposal sites. The depth to ground water ranges from 55 to 95 m on the

200-Area Plateau. The bottom of the unconfined aquifer is the uppermost basalt surface or, in some areas, the clays of the lower Ringold unit. The thickness of the unconfined aquifer in the 200 Areas ranges from less than 15 to 61 m. Beneath the unconfined aquifer is a confined aquifer system consisting of sedimentary interbeds or interflow zones that occur between dense basalt flows or flow units.

The sources of natural recharge to the unconfined aquifer are rainfall from areas of high relief to the west of the Hanford Site and the ephemeral streams, Cold Creek and Dry Creek. From the areas of recharge, the ground water flows downgradient and discharges into the Columbia River. This general flow pattern is modified by basalt outcrops and subcrops in the 200 Areas and by artificial recharge.

The unconfined aquifer beneath the 200 Areas receives artificial recharge from liquid disposal areas. Cooling water disposed to ponds has formed ground-water mounds beneath three high-volume disposal sites: the former U Pond in the 200-West Area, B Pond east of the 200-East Area, and Gable Mountain Pond north of the 200-East Area. The water table has risen approximately 20 m under the former U Pond and 9 m under B Pond compared with pre-Hanford conditions (Newcomb et al. 1972). During 1984, U Pond was deactivated and part of Gable Mountain Pond was backfilled in preparation for deactivation (Law and Schatz 1986).

The dry nature (i.e., climate, waste form, depth-to-water, etc.) of the low-level burial ground (LLBG) and the limited natural surface recharge available from precipitation minimizes the probability of leachate formation and migration from these facilities. Based on limited ground-water monitoring data, there is no evidence, to date, that any contaminants have moved from the LLBG to the ground water.

Characterization and revised ground-water monitoring of the 200 Area is currently planned to demonstrate compliance under the Resources Conservation and Recovery Act (RCRA). This action will supply additional information on the 200 Area.

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4.2.10 300 Area

Three geologic formations have been identified during drilling operations conducted in the 300 Area. These are, in ascending order, the Columbia River Basalt Group, the Ringold Formation, and the glaciofluvial sediments (Pasco gravels and Touchet beds) known informally as the Hanford formation (see Figure 4.2-8).

The Columbia River basalts are of Miocene age and form the bedrock beneath the Hanford Site, which includes the 300 Area. The middle-to-upper-Miocene subgroup is called the Yakima Basalt and is about 10.5 to 16.5 million years old (Myers et al. 1979). These flood basalts were extruded from fissure systems in the eastern and southern portions of the Columbia Plateau (Swanson et al. 1979). The individual flows comprising the formation range in thickness from about 3 to 48 m and are sometimes separated by sedimentary interbeds. The basalts were originally flat-lying, broad synclinal structures but have been locally warped and folded, producing anticlinal ridges and valleys. The Pasco syncline is a broad depression of basalt flows in the southeastern part of the Pasco Basin (Myers et al. 1979). The 300 Area is located in this syncline. At the 300 Area the top of the basalts is at a depth of about 60 m below land surface.

The Saddle Mountains Basalt is the uppermost formation of the Columbia River Basalt Group and is generally found in wells in the 300 Area at an elevation of about 63 m (207 ft) above mean sea level. However, in well 399-1-18C, in the north end of the 300 Area and north of the Process Trenches, the basalt was encountered at a higher elevation of 73 m (240 ft) above mean sea level. This basalt was identified as the Goose Island flow, overlying the Martindale flow of the Ice Harbor Member, which is generally the uppermost basalt flow beneath the 300 Area. The Goose Island flow is also part of the Ice Harbor Member but only exists in the northern part of the 300 Area, which accounts for the fact that basalt was encountered at a higher elevation in the north part of the area.[a]

(a) Data from "Interim Characterization Report for the 300 Area Surrounding the 300 Area Process Trenches." November 1987 Draft.

The Ringold Formation overlies the basalts. This formation is of Pliocene age (approximately 3 to 5 million years old -- Gustafson 1978) and with the exception of a weakly consolidated conglomerate member (Middle Ringold), consists mainly of layered silts, clays, and fine sands deposited in a lacustrine environment. The conglomerate member is considered to have been deposited in a high-energy fluvial environment. Distinctive lithologic zones within this formation in the southeastern portion of the Hanford Site include: 1) blue and green silts and clays of the lower Ringold unit, and 2) a conglomerate consisting of well-rounded pebbles and cobbles, with, medium-to-fine sand filling the interstitial spaces (Newcomb et al. 1972). Geologic logs of fine sand filling the interstitial spaces (Newcomb et al. 1972). Geologic logs of wells indicate that in the 300 Area the Ringold Formation consists of a series of sandy silt and clay layers but typically contains more than one permeable conglomerate or sand unit. Some of the silt layers are really continuous over much of the 300 Area. Ringold Formation thickness in this area is characteristically about 37 m.

Overlying the Ringold Formation are the glaciofluvial sediments, which are coarse clastic deposits laid down by the ancestral Columbia River when it was swollen by glacial meltwater (Newcomb et al. 1972). Drilling logs for wells in the 300 Area show this formation to consist of unconsolidated gravels and sands with some boulders and cobbles. A few of the drilling logs indicate a small amount of intermixed silt. Based on information from existing wells, the contact between the Ringold Formation and the glaciofluvial sediments in the 300 Area varies from about 14 to 18 m below the land surface and is distinguished by a change from sandy cobble and gravels to somewhat lighter-colored, finer gravels with layers of silt.

Eolian (wind transported and deposited) material overlies the glaciofluvial sediments and consists of unsaturated silt and fine-to-medium sand. These deposits vary from 0.3 to 4 m in thickness with a range of from 0.6 to 1.8 m being most typical. The geologic contact between the eolian deposits and the underlying glaciofluvial sediments is quite distinct.

Both unconfined and confined aquifers are present beneath the 300 Area. The uppermost aquifer is unconfined and is most likely to be affected by the 300 Area Process Trenches. Underlying aquifers are contained in the basalts and are generally confined.

The aquifers in the basalts consist primarily of permeable zones at the contacts of between basalt flows. The permeable zones, or interflow zones, are fractured vesicular basalt that occur at the upper and/or lower surfaces of the individual basalt flows and are the primary conduits for ground water. Sand or gravel interbeds may also be present in the interflow zones and serve as conduits for ground water.

In the 300 Area, the water table (the upper surface of the unconfined aquifer) is in the glaciofluvial sediments. The lower part of the unconfined aquifer, which may be partially confined, is in the Ringold Formation. The water table is at a depth of about 12 m below the land surface and the top of the Ringold Formation at a depth of 14 to 20 m.

Natural recharge of the unconfined aquifer beneath the Hanford Site occurs at the northwest margin of the Pasco Basin; most of the artificial recharge occurs at the 200 Areas near the center of the Hanford Site. Ground water flows from these recharge areas toward the 300 Area in a general southeasterly direction. In the southeast corner of the Hanford Site, groundwater recharge is mainly from the Yakima River. The 300 Area is located approximately at the point where these two ground-water sources meet. As a result, ground water enters the 300 Area from the northwest, west, and southwest (Lindberg and Bond 1979).

Near the process trenches ground water generally flows toward the river to the southeast and east. Exact direction of ground-water flow at any given time is determined by both natural and man-caused influences. The primary natural influence is the level of water in the Columbia River. Lindberg and Bond (1979) verified that when the river stage rises during spring run-off, bank storage occurs and causes a reversed water-table gradient in the 300 Area. During these times, ground water tends to flow in a more southeasterly direction in a direction roughly subparallel to the river. When the river level drops, the natural gradient is restored and ground water flows more easterly in a direction nearly perpendicular to the river.

Characterization of the 300 Area Process Trenches and ground-water monitoring for RCRA compliance is currently under way. Field data collection has been completed and additional data will be available in the near future.

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4.3 ECOLOGY

The Hanford Site is made up of relatively large, undisturbed expanses of shrub-steppe desert that contain numerous plant and animal species suited to the region's semiarid environment. The Hanford Site consists of mostly undeveloped land with widely spaced clusters of industrial buildings located along the western shoreline of the Columbia River and at several locations in the interior of the 1450 km^2 Hanford Site. The industrial buildings are interconnected by roads, railroads, and electrical transmission lines. The major facilities and activities occupy only about 6% of the total available land area, and the surrounding wildlife is not very affected by these facilities. Most of the Hanford Site has not experienced tillage or livestock grazing since the early 1940s. The Columbia River flows through the Hanford Site, and although the river flow is not directly impeded by artificial dams within the Hanford Site, the historical daily and seasonal water fluctuations have been changed by dams upstream and downstream of the Site (Rickard and Watson 1985). The Columbia River and other water bodies on the Hanford Site provide habitat for aquatic organisms, and the Columbia is accessible for public recreational use and commercial navigation. Other descriptions of the ecology of the Hanford Site can be found in ERDA (1975), Rogers and Rickard (1977), Jamison (1982), and Watson et al. (1984), among others.

4.3.1 Terrestrial Ecology

Vegetation

The Hanford Site, located in southeastern Washington, has been characterized as a cool desert or a shrub-steppe (Daubenmire 1970). Because of the aridity, the productivity of both plants and animals is relatively low compared to that of other natural communities. In the early 1800s, the dominant plant was big sagebrush with an understory of perennial bunchgrasses, especially Sandberg's bluegrass and bluebunch wheatgrass. With the advent of settlement that brought livestock grazing and crop raising, the natural vegetation mosaic was opened to a persisting invasion by alien annuals, especially cheatgrass. Today cheatgrass is the dominant plant on cultivated fields that were abandoned 40 years ago. Cheatgrass is also well established on rangelands at elevations 244 m (Rickard and Rogers 1983). Although the dryland areas of the Hanford Site were treeless in the years before land settlement, trees were planted and irrigated on farms to provide windbreaks and shade for several decades before 1943. When these farms were abandoned in 1943, some of the trees died but others have persisted, presumably because their roots are deep enough to contact ground water. Today these trees serve as nesting platforms for several species of birds, including hawks, owls, ravens, magpies, and great blue herons, and as night roosts for wintering bald eagles (Rickard and Watson 1985). Today, the vegetation mosaic of the Hanford Site consists of eight major kinds of plant communities:

- sagebrush/bluebunch wheatgrass
- sagebrush/cheatgrass or sagebrush/Sandburg's bluegrass
- sagebrush-bitterbrush/cheatgrass
- greasewood/cheatgrass-saltgrass
- winterfat/Sandberg's bluegrass
- thyme buckwheat/Sandberg's bluegrass
- cheatgrass-tumble mustard
- willow.

The distribution of the dominant plant communities is shown in Figure 4.3-1, and a list of common plants is given in Table 4.3-1.

The release of water used as industrial process coolant streams at the Hanford Site facilities has created several semipermanent artificial water bodies at places that had never before supported them. Over the years, they have developed stands of cattails, reeds, and trees, especially willow, cottonwood, and Russian olive. These ponds are ephemeral and will disappear if the industrial release of water is terminated.

Over 240 species of plants have been identified on the Hanford Site (ERDA 1975). The dominant plants on the 200-Area Plateau are big sagebrush, rabbitbrush, cheatgrass, and Sandberg's bluegrass, with cheatgrass providing half of the total plant cover. Cottonwood, willows, cattails, and bullrushes grow along ponds and ditches. Near the 100 Areas, cheatgrass and riparian plants are the most prevalent; and big sagebrush, bitterbrush, rabbitbrush, cheatgrass and Sandberg's bluegrass are common in the 300 and 400 Areas.

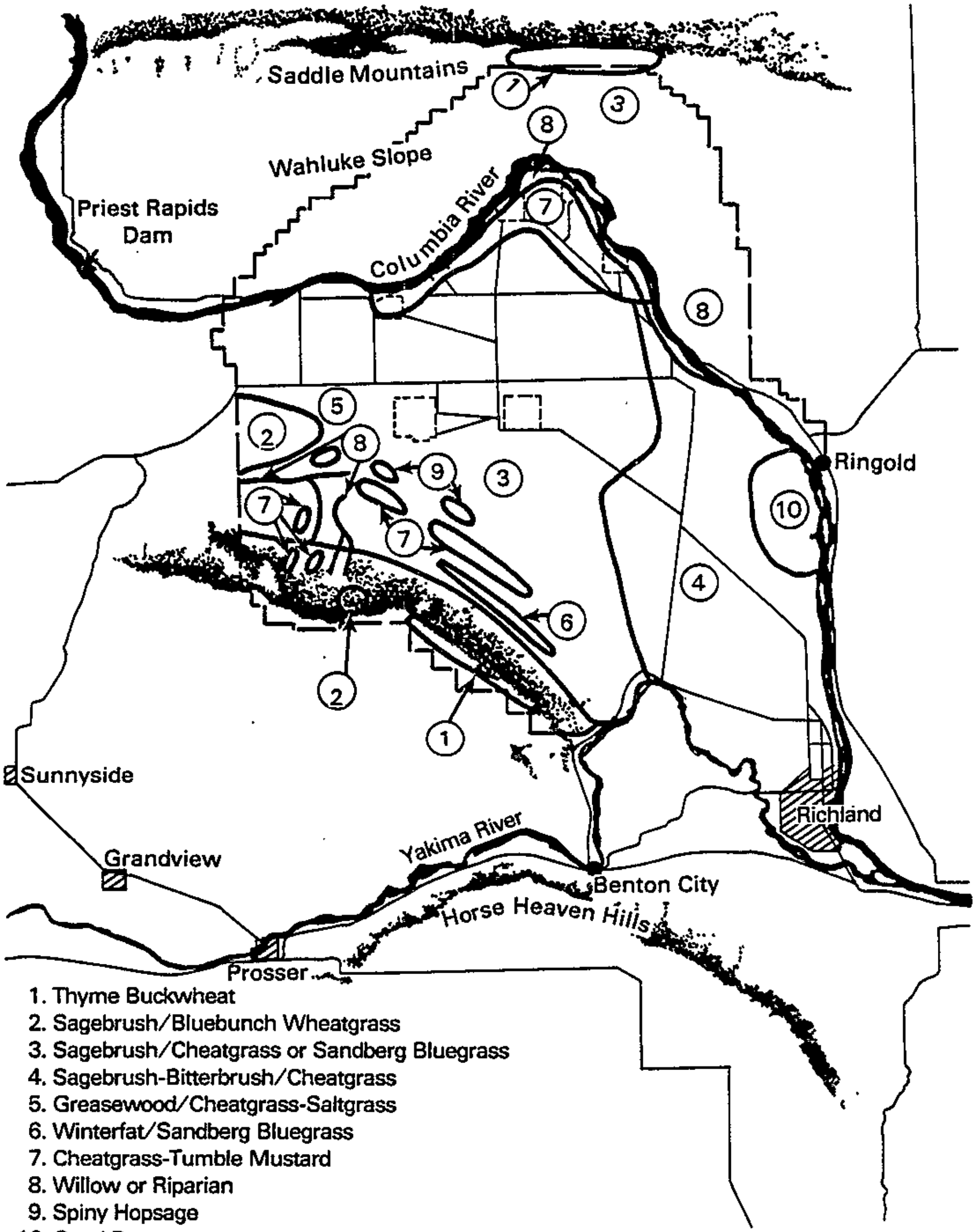

FIGURE 4.3-1. Distribution of Vegetation Types on the Hanford Site

TABLE 4.3-1. Prominent Vegetation on the Hanford Site

Common Name	Scientific Name
Big sagebrush	*Artemisia tridentata*
Bitterbrush	*Purshia tridentata*
Gray rabbitbrush	*Crysothamnus nauseous*
Hopsage	*Atriplex spinosa*
Willow	*Salix* sp.
Russian olive	*Elaeagnus angustifolia*
Cottonwood	*Populus* sp.
Needle-and-thread grass	*Stipa Comata*
Sandberg's bluegrass	*Poa sandbergii*
Bluebunch wheatgrass	*Agropyron spicatum*
Cheatgrass	*Bromus tectorum*
Canary grass	*Phalaris arundinacea*
Three-awn	*Aristida* spp.
Carex	*Carex* spp.
Horsetail	*Equisetum* spp.
Barnyard grass	*Echinochloa crusgallii*
Muhly grass	*Muhlenbergia* sp.
Indian ricegrass	*Oryzopsis hymenoides*
Old witchgrass	*Panicum* sp.
Cattail	*Typha latifolia*
Sand dropseed	*Sporobolus cryptandrus*
Astragalus	*Astragalus* spp.
Bassia	*Bassia hyssopsfolia*
Tansy mustard	*Descurainia pinnata*
Wild lettuce	*Lactuca serriola*
Bladderpod	*Lesquerrella* sp.
Lupine	*Lupinus* spp.
White sweet clover	*Melitotus alba*
Microsteris	*Microsteris* sp.
Evening-primrose	*Oenothera* spp.
Phlox	*Phlox longiflora*
Prickly pear	*Opuntia polycantha*
Indian wheat	*Plantago purshii*

TABLE 4.3-1. (contd)

Common Name	Scientific Name
Willow-weed	*Epilobium paniculatum*
Russian thistle	*Salsola kali*
Jim Hill mustard	*Sisymbrium altissimum*
Goldenrod	*Soldidago* spp.
Globe mallow	*Sphaeralcea munroana*
Buttercup	*Ranunculus* spp.
Common mullen	*Verbascum thapsus*

Over 100 species of plants have been identified in the 200-Area Plateau (ERDA 1975). Cheatgrass and Russian thistle, annuals introduced to the United States from Eurasia in the late 1800s, invade areas where the ground surface has been disturbed. A food web centered on cheatgrass is shown in Figure 4.3-2 (modified from Watson et al. 1984). Certain desert plants have roots that grow to depths approaching 10 m (Napier 1982). However, root penetration to these depths has not been demonstrated for plants in the 200 Areas. Rabbitbrush roots have been found at a depth of 2.4 m near the 200 Areas (Klepper et al. 1979). Mosses and lichens appear abundantly on the soil surface; lichens commonly grow on the shrub stems.

Insects

More than 300 species of terrestrial and aquatic insects have been found on the Hanford Site (ERDA 1975). The grasshoppers and the darkling beetles are among the more conspicuous groups and, along with other species, are important in the food web of the local birds and mammals. Most species of darkling beetles occur throughout the spring to fall period, although some species are present only during 2 or 3 months in the fall (Rogers and Rickard 1977). Grasshoppers are evident during the late spring to fall. Both groups are subject to wide annual variations in abundance. A food web centered on grasshoppers is shown in Figure 4.3-3 (Watson et al. 1984).

An estimation of the relative densities of various insect taxa in three plant communities is given in Table 4.3-2.

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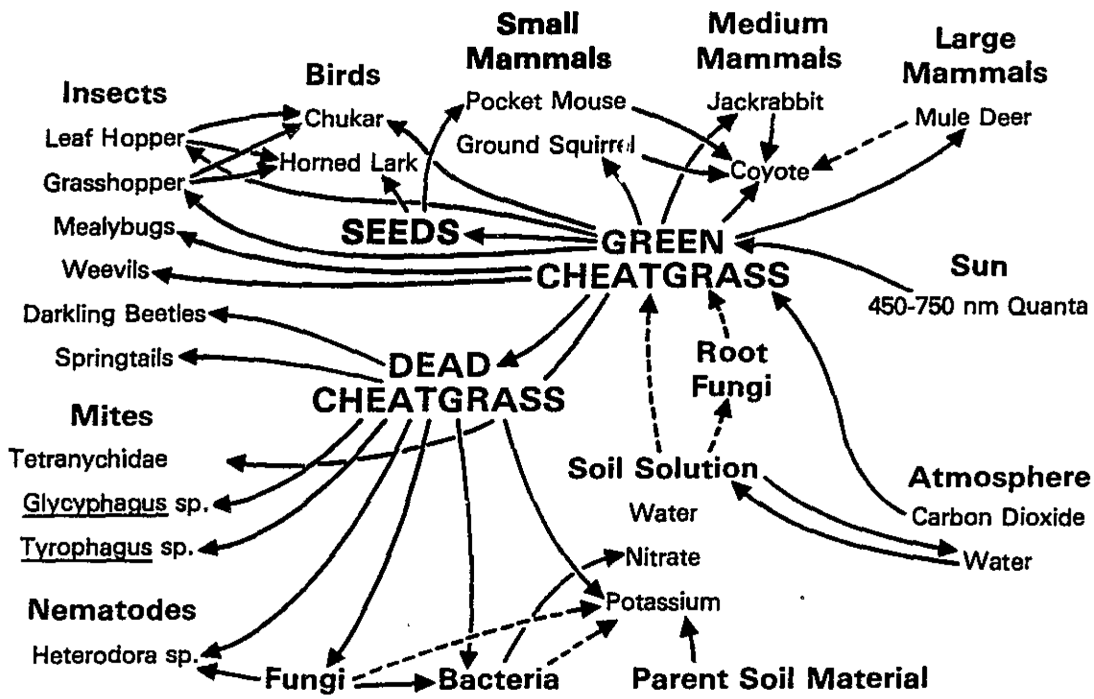

FIGURE 4.3-2. Food Web Centered on Cheatgrass (Arrows indicate direction of energy and mass transfer)

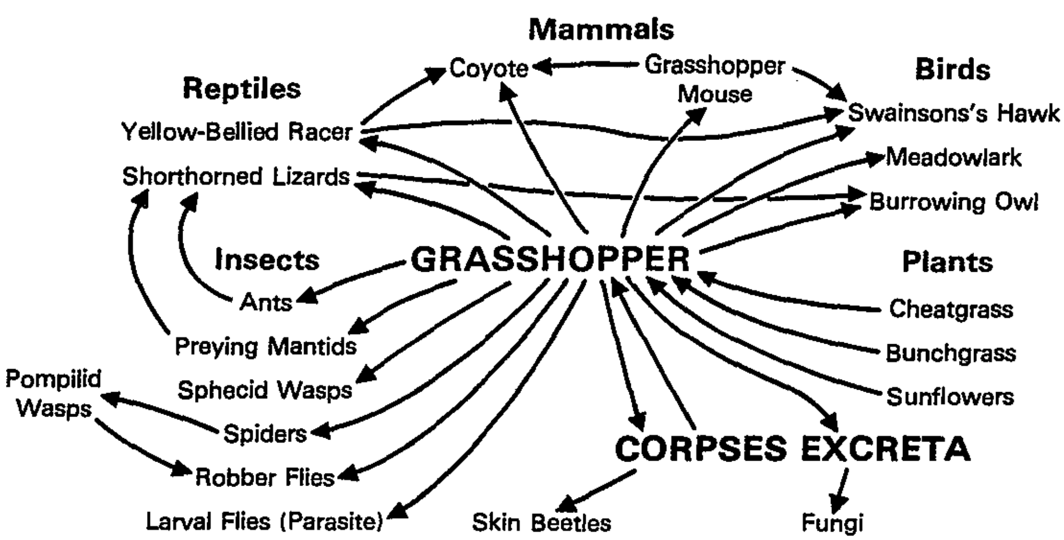

FIGURE 4.3-3. Food Web Centered on Grasshopper (Arrows indicate direction of energy and mass transfer)

TABLE 4.3-2. Relative Abundance (%) of Insect Taxa Collected from Sagebrush, Rabbitbrush, and Hopsage (Rogers 1979)

Taxa	Sagebrush	Rabbitbrush	Hopsage
Hemipptera	44.6	11.7	6.4
Homoptera	33.0	31.2	6.1
Orthoptera	7.3	24.0	21.8
Araneida	6.5	20.7	21.3
Hymenoptera	4.2	2.9	5.8
Coleoptera	1.7	1.9	27.4
Lepidopt era	1.2	6.1	5.3
Diptera	1.1	1.2	5.3
Neuroptera	0.3	0.3	0.3
Other	0.1	0.1	0.3

Reptiles and Amphibians

Approximately 16 species (Table 4.3-3) of amphibians and reptiles have been observed at the Hanford Site (ERDA 1975). The occurrence of the species infrequent when compared with the similar fauna of the southwestern United States. The side-blotched lizard is the most abundant reptile and can be found throughout the Hanford Site. Horned and sagebrush lizards are also common. The most common snake is the gopher snake; the yellow-bellied racer found throughout the Hanford Site. Horned and sagebrush lizards are also common. The most common snake is the gopher snake; the yellow-bellied racer and the Pacific rattlesnake are also common. Striped whipsnakes and desert night snakes are found occasionally and are important food items for birds of prey. Toads and frogs are found near the permanent water bodies or along the Columbia River.

Birds

Over 125 species of birds have been identified from the Hanford Site (Rogers and Rickard 1977). The horned lark and western meadowlark are the most abundant nesting birds in the shrub-steppe. Some of the more common birds present on the Hanford Site are listed in Table 4.3-4.

TABLE 4.3-3. Amphibians and Reptiles Occurring on the Hanford Site

Common Name	Scientific Name
Amphibians	
Great Basin spadefoot toad	Scaphiopus intermountanus
Western toad	Bufo boreas
Pacific treefrog	Hyla regilla
Spotted frog	Rana pretiosa
Leopard frog	Rana pipiens
Bullfrog	Rana catesbeiana
Reptiles	
Sagebrush lizard	Sceloporus graciosus
Side-blotched lizard	Uta stansburiana
Short-horned lizard	Phrynosoma douglassi
Striped whipsnake	Masticophis taeniatus
Western yellow-bellied racer	Colluber constrictor
Gopher snake	Pituophis melanoleucos
Garter snake	Thamnophis elegans
Desert night snake	Hyspiglena torquata
Pacific rattlesnake	Crotalus viridis

The Hanford Site supports populations of chukar partridge, gray partridge, and sage grouse. The greatest concentrations of these birds are in the Rattlesnake Hills. The sage grouse population is very small and appears to be confined entirely to the slopes of the Rattlesnake Hills. The mourning dove nests throughout the Hanford Site. Small isolated populations of Chinese ring-necked pheasants and California quail live along the Columbia River and near the spring-streams in the Rattlesnake Hills. A food web centered on chukar partridge is shown in Figure 4.3-4 (Watson et al. 1984).

Wastewater ponds at the Hanford Site are important habitats for song-birds, shore birds, ducks, and geese (Fitzner and Price 1973, Fitzner and Rickard 1975, Fitzner and Schreckhise 1979). The American coot is the most abundant nesting bird on these sites. The ponds are frequently used by a variety of waterfowl during fall migration. The most important resident waterfowl is the Canada goose, whose nesting habitat is confined to the

TABLE 4.3-4. Partial List of the Common Birds Found on the Hanford Site

Common Name	Scientific Name
Great blue heron	Ardea herodias
Canada goose	Branta canadensis moffitti
Mallard	Anas platyrhynchos
Red-tailed hawk	Buteo jamaicensis
Swainson's hawk	Buteo swainsoni
Rough-legged hawk	Buteo lagopus
Sharp tailed grouse	Pedioecetes phasinaellis
Sage grouse	Centrocereus urophasianus
California quail	Lophortyx californicus
Ring-necked pheasant	Phasianus colchicus
Chukar partridge	Alectoris chukar
Gray (Hungarian) partridge	Perdix perdix
American coot	Fulica americana
California gull	Larus californicus
Ring-billed gull	Larus delawarensis
Mourning dove	Zenaidura macroura
Horned lark	Eremophila alpestris
Black-billed magpie	Pica pica
Western meadowlark	Sturnella neglecta
Sage sparrow	Amphispiza belli

islands of the free-flowing reach of the Columbia River (Hanson and Eberhardt 1971). Forester's tern and ring-billed and California gulls also nest on the islands. The Columbia River also serves as a major resting area for migrant waterfowl. The greatest concentrations of ducks and geese occur in the autumn months, and waterfowl hunting is a popular recreational activity where it is permitted. The Hanford Site is located in the Pacific Flyway; in addition, a major sandhill crane flyway passes over the site.

Hawks and owls use the Hanford Site as a refuge, especially during nesting (Fitzner et al. 1980).

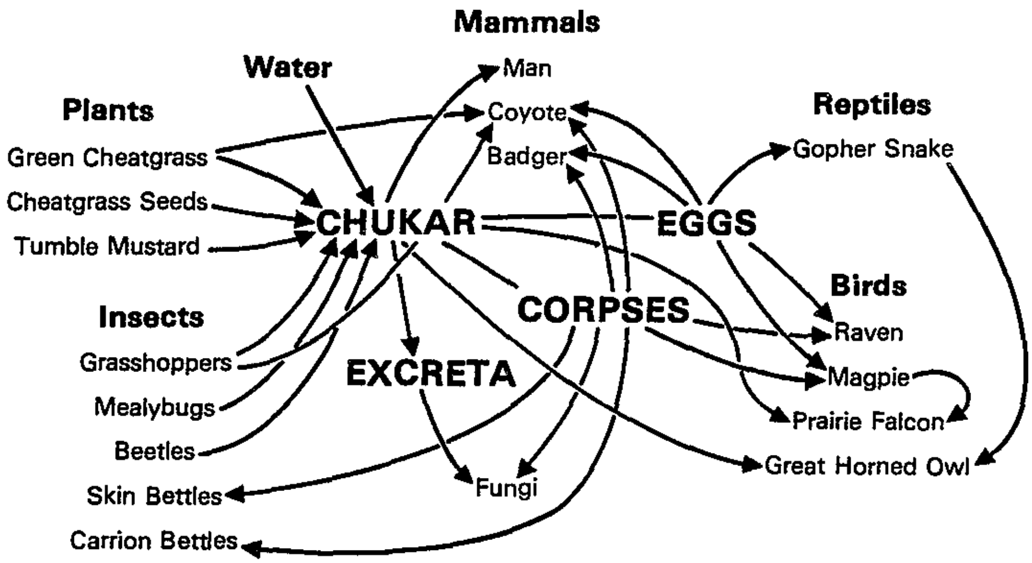

FIGURE 4.3-4. Food Web Centered on Chukar Partridge (Arrows indicate direction of energy and mass transfer)

Mammals

Approximately 30 species of mammals have been identified on the Hanford Site (Table 4.3-5). Most are small and nocturnal. Of this group, the Great Basin pocket mouse is the most abundant, and others include the deer mouse, Townsend ground squirrel, pocket gopher, harvest mouse, house mouse, Norway rat, sagebrush vole, grasshopper mouse, vagrant shrew, least chipmunk, and Merriam vole. Cottontail rabbits are widely distributed throughout the dryland habitats of the Hanford Site, and the black-tailed jackrabbit is found scattered throughout the lower elevations of the Hanford Site.

Muskrats and porcupines have been observed along the shorelines of the ponds and ditches, and beavers are resident of the sloughs along the Columbia River. Raccoons, skunks, bobcats, mink, and badgers are also present. The coyote is the principal mammalian predator on the Hanford Site.

Larger mammals found include the mule deer and elk. The herd of wild, free-roaming elk is centered almost entirely on the Arid Lands Ecology (ALE)

TABLE 4.3-5. List of Mammals Occurring on the Hanford Site (Rogers and Rickard 1977)

Common Name	Scientific Name
Merriam shrew	*Sorex merriami*
Vagrant shrew	*Sorex vagrans*
Little brown bat	*Myotis lucifugus*
Silver-haired bat	*Lasionycteris noctivagans*
Fringed myotis bat	*Myotis thysanodes*
California myotis bat	*Myotis californicus*
Small-footed myotis bat	*Myotis subulatus*
Hairy-winged myotis bat	*Myotis volans*
Long-eared myotis bat	*Myotis erotis*
Big brown bat	*Eptesicus fuscus*
Western pipistrelle bat	*Pipistrellus hesperus*
Pallid bat	*Antrozous pallidus*
Lump-nosed bat	*Plecotus townsendii*
Hoary bat	*Lasiurus cinereus*
Raccoon	*Procyon lotor*
Mink	*Mustela vison*
Long tailed weasel	*Mustela frenata*
Badger	*Taxidea taxis*
Striped skunk	*Mephitis mephitis*
Coyote	*Canis latrans*
Bobcat	*Lynx rufus*
Least chipmunk	*Eutamias minimus*
Townsend's ground squirrel	*Citellus townsendii*
Northern pocket gopher	*Thomomys talpoides*
Great Basin pocket mouse	*Perognathus parvus*
Beaver	*Castor canadensis*
Western harvester mouse	*Reithrodontomys megalotis*
Deer mouse	*Peromyscus maniculatus*
Northern grasshopper mouse	*Onychomys leucogaster*
Montana meadow mouse	*Microtus montanus*
Bushytail woodrat	*Neotoma cinerea*
Mountain vole	*Microtus montanus*

TABLE 4.3-5. (contd)

Common Name	Scientific Name
Sagebrush vole	*Lagurus curtatus*
Muskrat	*Ondatra zibethicus*
House mouse	*Mus musculus*
Norway rat	*Rattus norvegicus*
Porcupine	*Erethizon dorsatum*
Black-tailed jack rabbit	*Lepus californicus*
White-tailed hare	*Lepus townsendii*
Nuttall cottontail rabbit	*Sylvilagus nuttallii*
Mule deer	*Odocoileus hemionus*
Whitetailed deer	*Odocoileus virginianus*
Elk	*Cervus elaphus*

reserve, a part of the Hanford Site established as an environmental research study area in 1968. The mule deer are found mostly along the Columbia River and in the Rattlesnake Hills.

Twelve species of bats are also present on the Hanford Site (Rogers and Rickard 1977).

4.3.2 Aquatic Ecology

There are two types of natural aquatic habitats on the Hanford Site; one is the Columbia River, which flows along the northern and eastern edges of the Hanford Site, and the other are the small spring-streams located mainly on the ALE site in the Rattlesnake Hills. Several artificial water bodies, both ponds and ditches, have been formed as a result of wastewater disposal practices associated with the operation of the reactors and separation facilities. These are temporary and will vanish with cessation of activities, but while present, they form established aquatic ecosystems (except West Pond) complete with representative flora and fauna. West Pond is created by a rise in the water table in the 200 Areas and is not fed by surface flow; thus, it is alkaline and has a much restricted complement of biota.

The Columbia River

The Columbia River is the dominant aquatic ecosystem on the Hanford Site and supports a large and diverse community of plankton, benthic invertebrates, fish, and other communities. It is the fifth largest river in North America and has a total length of 1955 km from its origin in British Columbia to its mouth at the Pacific Ocean. The Columbia has been dammed both up- and downstream from the Hanford Site, and the reach flowing through the area is the last free-flowing, but regulated, reach of the Columbia in the United States. Plankton populations in the Hanford reach are influenced by communities that develop in the reservoirs of upstream dams, particularly Priest Rapids Reservoir, and manipulation of water levels below by dam operations in downstream reservoirs. Phytoplankton and zooplankton populations at Hanford are largely transient, flowing from one reservoir to another. There is generally insufficient time for characteristic edemic groups of phytoplankton and zooplankton to develop in the Hanford reach. No significant tributaries enter the Columbia during its passage through the Hanford Site.

The Columbia River is a very complex ecosystem because of its size, the number of manmade alterations, the diversity of the biota, and the size and diversity of its drainage basin. Streams in general, especially smaller ones, usually depend upon organic matter from outside sources (terrestrial plant debris) to provide energy for the ecosystem. Large rivers, particularly the Columbia with its series of large reservoirs, contain significant populations of primary energy producers (algae, plants) that contribute to the basic energy requirements of the biota. Phytoplankton (free-floating algae) and periphyton (sessile algae) are abundant in the Columbia River and provide food for herbivores such as immature insects, which in turn are consumed by carnivorous species. Figure 4.3-5 is a simplified diagram of the food-web relationships in selected Columbia River biota and represent probable major energy pathways.

Phytoplankton. Phytoplankton species identified from the Hanford reach include diatoms, golden or yellow-brown algae, green algae, blue-green algae, red algae, and dinoflagellates. Diatoms are the dominant algae in the Columbia River phytoplankton, usually representing over 90% of the populations. The main genera include *Asterionella*, *Cyclotella*, *Fragilaria*,

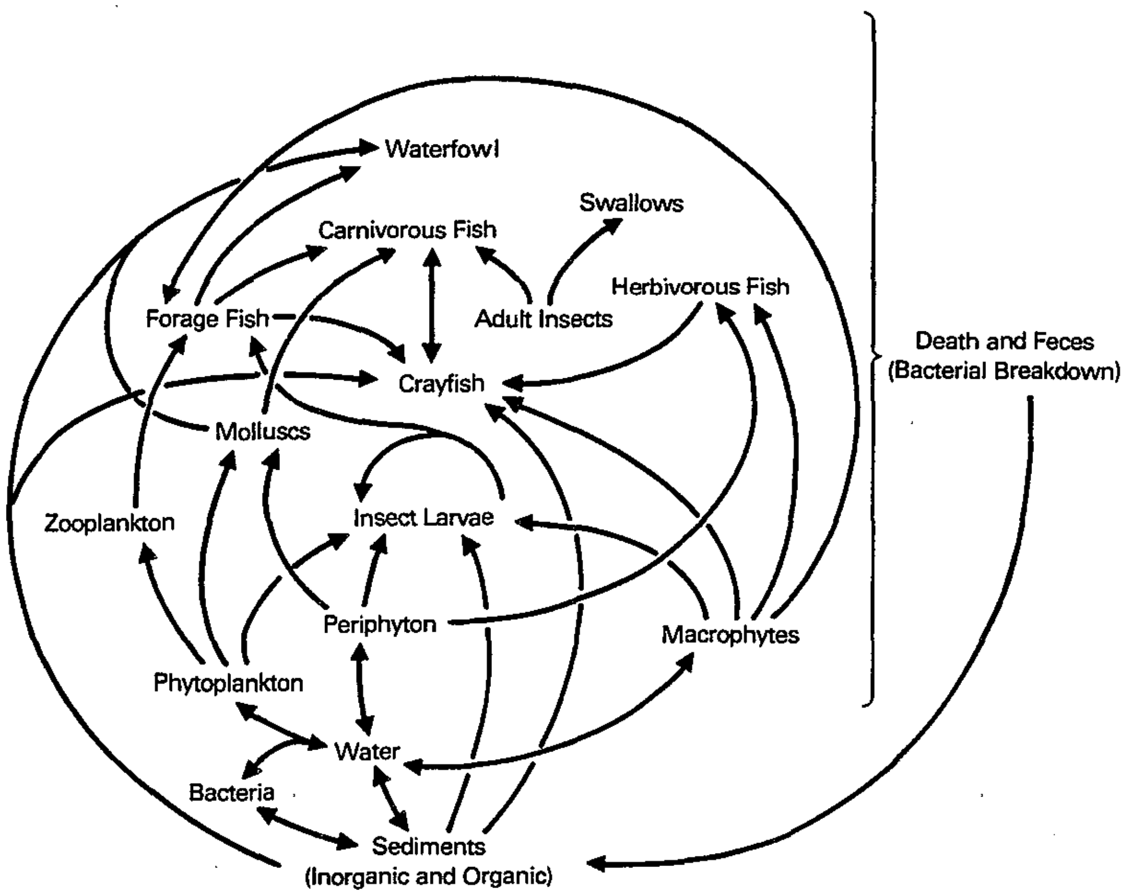

FIGURE 4.3-5. Food Web in the Columbia River

Melosira, *Stephandodiscus* and *Synedra* (Neitzel et al. 1982). These are typical of those forms found in lakes and ponds and originate in the upstream reservoirs. A number of algae found as free-floating species in the Hanford reach of the Columbia are actually derived from the periphyton; they are detached and suspended by the current and frequent fluctuations of the water level. The peak concentration of phytoplankton is observed in April and May, with a secondary peak in late summer/early autumn (Cushing 1967a). The spring pulse in phytoplankton density is probably related to increasing light and water temperature rather than to availability of nutrients because PO_4 and NO_3 nutrient concentrations are never limiting. Minimum numbers are present in December and January. Green algae (Chloroplyta) and blue-green algae (Cyanophyta) occur in the phytoplankton community during warmer months, but in substantially fewer numbers than the diatoms. Diversity indices, carbon uptake, and chlorophyll a concentrations for the phytoplankton at various times and places can be found in Wolf et al. (1976), Beak Consultants Inc. (1980), and Neitzel et al. (1982).

Periphyton. Communities of periphytic species ("benthic microflora") develop on suitable solid substrates wherever there is sufficient light for photosynthesis. Peaks of production occur in spring and late summer (Cushing 1967b). Dominant genera are the diatoms *Achnanthes*, *Asterionella*, *Cocconeis*, *Fragillaria*, *Gomphonema*, *Melosira*, *Nitzchia*, *Stephanadiscus* and *Synedra* (Page and Neitzel 1978, Page et al. 1979, Beak Consultants Inc. 1980, Neitzel et al. 1982).

Macrophytes. Macrophytes are sparce in the Columbia due to the strong currents, rocky bottom, and frequently fluctuating water levels. Rushes (*Juncus* spp.) and sedges (*Carex* spp.) occur along the shorelines of the slackwater areas such as the White Bluffs Slough, below 100-H Area, the slough area downstream of the 100-F Area, and the Hanford Slough. Macrophytes are also present along gently sloping shorelines that are subject to flooding during the spring freshet and daily fluctuating river levels (below Coyote Rapids and 100-D Area). Commonly found plants include *Lemna*, *Potamogeton*, *Elodea*, and *Myriophyllum*. Where they exist, macrophytes have considerable ecological value. They provide food and shelter for juvenile fish and spawning areas for some species of warm-water game fish.

Zooplankton. The zooplankton populations in the Hanford reach of the Columbia are generally sparce. In the open water regions, crustacean zooplankters are dominant. Dominant genera are *Bosmina*, *Diaptomus*, and *Cyclops*. Densities are lowest in winter and highest in the summer. Summer peaks are dominated by *Bosmina* and range up to 4500 organisms/m^3. Winter densities are generally less than 50 organisms/m^3. *Diaptomus* and *Cyclops* dominate in winter and spring, respectively (Neitzel et al. 1982).

Benthic Organisms. Benthic organisms are found either attached to or closely associated with the substrate. All major freshwater benthic taxa are represented in the Columbia River. Insect larvae such as caddisflies (Trichoptera), midge flies (Chironomidae), and black flies (Simuliidae) are dominant. Dominant caddisfly species are *Hydropsyche cockerelli*, *Cheumatopsyche campyla* and *C. enonis*. Other benthic organisms include limpets, snails, sponges, and crayfish. Peak larval insect densities are found in late fall and winter, and the major emergence is in spring and summer (Wolf 1976). Stomach contents of fish collected in the Hanford reach from June 1973 through March 1980 revealed that benthic invertebrates are important food items for nearly all juvenile and adult fish. There is a close relationship between food organisms in the stomach contents and those in the benthic and invertebrate drift communities.

Fish. Gray and Dauble (1977) list forty-three species of fish in the Hanford reach of the Columbia River; since then, the brown bullhead (*Ictalurus nebulosus*) has been collected bringing the total number of fish species identified in the Hanford reach to forty-four (Table 4.3-6). Of these, the chinook salmon, sockeye salmon, coho salmon, and steelhead trout use the river as a migration route to and from upstream spawning areas and are of the greatest economic importance. Both the fall chinook salmon and steelhead trout also spawn in the Hanford reach. Since 1962, the Hanford reach spawning population has represented about 15 to 20% of the total fall chinook escapement to the river. The destruction of other main-stream Columbia spawning grounds by dams has increased the relative importance of the Hanford spawning reach (Watson 1970, 1973).

The annual average Hanford reach steelhead spawning population estimates for the years 1962 to 1971 were about 10,000 fish. The estimated annual sport catch for the period 1963 to 1968 in the reach of the river from Ringold to the mouth of the Snake River was approximately 2,700 fish (Watson 1973).

The shad, another anadromous species, may also spawn in the Hanford reach of the river. The upstream range of the shad has been increasing since 1956 when fewer than 10 adult shad ascended McNary Dam. Since then, the number ascending Priest Rapids Dam, immediately upstream from Hanford, has risen to many thousands each year and the young-of-the-year have been collected in the Hanford reach. The shad is not dependent upon specific current

TABLE 4.3-6. Fish Species in the Hanford Reach of the Columbia River

Common Name	Scientific Name
White sturgeon	*Acipenser transmontanus*
Bridgelip sucker	*Catostomus columbianus*
Largescale sucker	*Catostomus macrocheilus*
Mountain sucker	*Catostomus platyrhynchus*
Pumpkinseed	*Lepomis gibbosus*
Bluegill	*Lepomis macrochirus*
Smallmouth bass	*Micropterus dolomieui*
Largemouth bass	*Micropterus salmoides*
White crappie	*Pomoxis annularis*
Black crappie	*Pomoxis nigromaculatus*
American shad	*Alosa sapidissima*
Prickley sculpin	*Cottus asper*
Mottled sculpin	*Cottus bairdi*
Piute sculpin	*Cottus beldingi*
Reticulate sculpin	*Cottus perplexus*
Torrent sculpin	*Cottus rotheus*
Chiselmouth	*Acrocheilus alutaceus*
Carp	*Cyprinus carpio*
Peamouth	*Mylocheilus caurinus*
Northern squawfish	*Ptychocheilus oregonensis*
Longnose dace	*Rhinichthys cataractae*
Leopard dace	*Rhinichthys falcatus*
Speckled dace	*Rhinichthys osculus*
Redside shiner	*Richardsonius balteatus*
Tench	*Tinca tinca*
Burbot	*Lota lota*
Threespine stickleback	*Gasterosteus aculeatus*
Black bullhead	*Ictalurus melas*
Yellow bullhead	*Ictalurus natalis*
Brown bullhead	*Ictalurus nebulosus*
Channel catfish	*Ictalurus punctatus*
Yellow perch	*Perca flavescens*
Walleye	*Stizostedion vitreum vitreum*

TABLE 4.3-6. (contd)

Common Name	Scientific Name
Sand roller	*Percopsis transmontana*
Pacific lamprey	*Entosphenus tridentatus*
River lamprey	*Lampetra ayresi*
Lake whitefish	*Coregonus clupeaformis*
Coho salmon	*Oncorhynchus kisutch*
Sockeye salmon	*Oncorhynchus nerka*
Chinook salmon	*Oncorhynchus tshawytscha*
Mountain whitefish	*Prosopium williamsoni*
Cutthroat trout	*Salmo clarki*
Rainbow trout (steelhead)	*Salmo gairdneri*
Dolly Varden	*Salvelinus malma*

and bottom conditions required by the salmonids for spawning and has apparently found favorable conditions for reproduction throughout much of the Columbia and Snake rivers.

Other fish of importance to sport fishermen are the whitefish, sturgeon, smallmouth bass, crappie, catfish, walleye, and perch. Large populations of rough fish including carp, shiners, suckers, and squawfish are also present.

Spring Streams

The small spring streams, such as Rattlesnake and Snively springs, contain diverse biotic communities and are extremely productive (Cushing and Wolf 1984). Dense blooms of watercress occur which are not lost until one of the major flash floods occurs. The aquatic insect production is fairly high as compared to mountain streams (Gaines 1987). The macrobenthic biota varies from site to site and is related to the proximity of colonizing insects and other factors.

Rattlesnake Springs on the western side of the Hanford Reservation forms a small surface stream that flows for about 2.5 km (1.6 mi) before disappearing into the ground, as a result of seepage and evapotranspiration. Base flow of this stream is about 0.01 m^3/sec (0.4 cfs) (Cushing and Wolf 1982). Water temperature ranges from 2 to 22°C (36 to 72°F). Mean annual total alkalinity (as $CaCO_3$), nitrate nitrogen, phosphate phosphorous, and total dissolved solids are 127, 0.3, 0.18, and 217 mg/L (Cushing et al. 1980; Cushing and Wolf 1982). The sodium content of the spring water is about 7 ppm (Brown 1970). It is of ecological importance because it provides a source of water to terrestrial animals in an otherwise arid part of the reservation. Snively Springs, located farther west and at a higher elevation than Rattlesnake Springs, apparently does not contribute to the flow of Rattlesnake Springs (Brown 1970), but probably flows to the west and off the Site. The major rooted aquatic plant, which in places may cover the entire width of the stream, is watercress (Rorippa nasturtium-aquatica). Isolated patches of bulrush (Scirpus sp.), spike rush (Eleocharis sp.), and cattail (Typha latifolia) occupy less than 5% of the stream bed.

Primary productivity at Rattlesnake Springs was greatest during the spring and coincident with the maximum periphyton standing crop. Net primary productivity averaged 0.9 $g{\cdot}Cm^{-2}{\cdot}d^{-1}$ during 1969-1970; the spring maximum was 2.2 $g{\cdot}Cm^{-2}{\cdot}d^{-1}$. Seasonal productivity and respiration rates are within the ranges reported for arid region streams. Although Rattlesnake Springs was a net exporter of organize matter during much of the growing season, it is subject to flash floods and severe scouring and denuding of the stream bed during winter and early spring, making it an importer of organic materials on an annual basis (Cushing and Wolf 1984).

An inventory of the many springs occurring on the Rattlesnake Hills has been published by Schwab et al. (1979). Limited physical and chemical data are included for each site.

Temporary Water Bodies

The temporary waste water ponds and ditches have been in place for as long as two decades. Rickard et al. (1981) have discussed the ecology of Gable Mountain Pond, one of the former major lentic sites. Emery and McShane (1980) have presented the ecological characteristics of all of the temporary sites. The ponds develop luxuriant riparian communities and become quite attractive to autumn and spring migrating birds; several species nest in the vicinity of the ponds. Some of these ponds and ditches are shown in Figure 4.3-6.

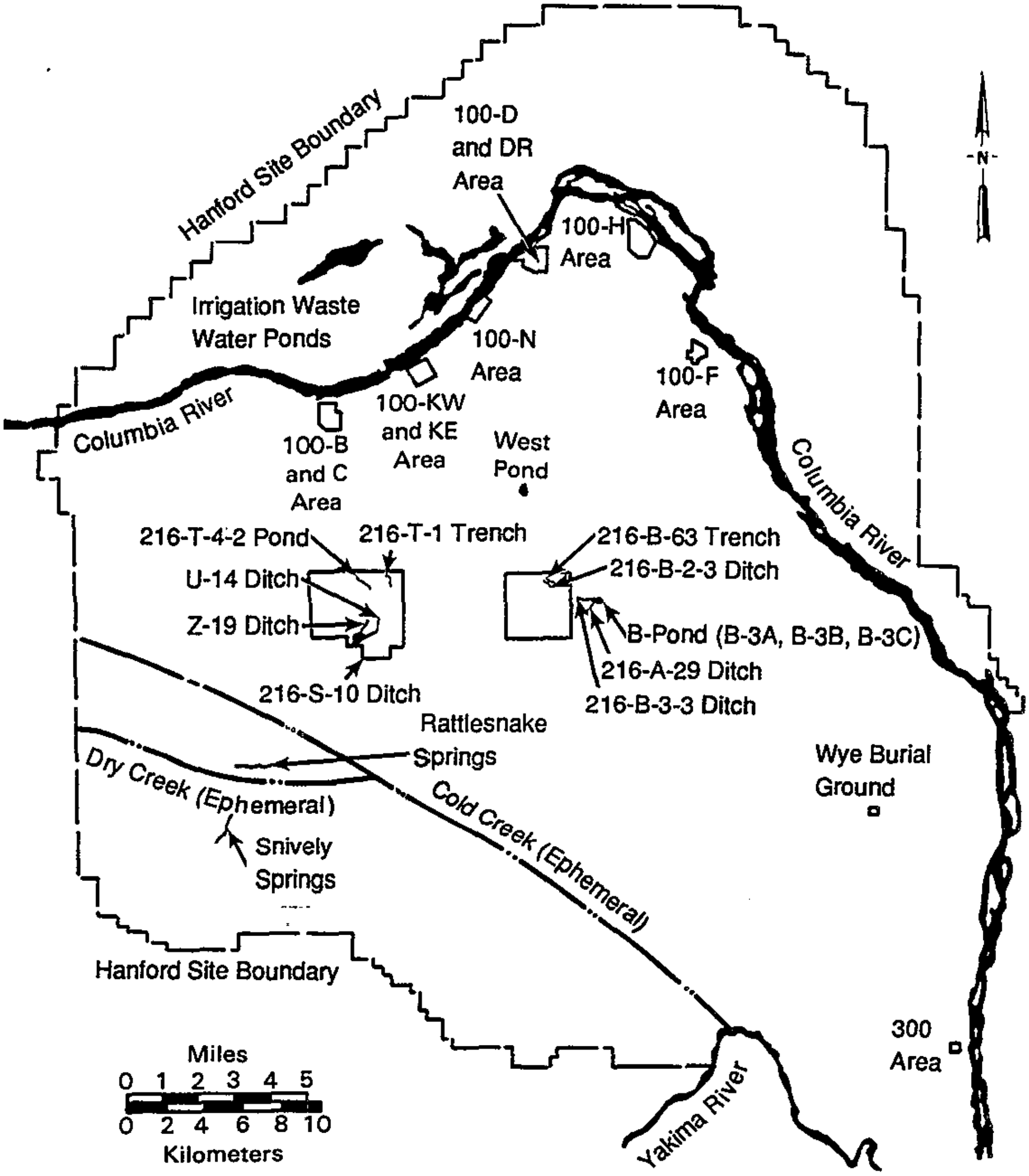

FIGURE 4.3-6. Temporary Ponds and Ditches, Including Ephemeral Streams on the Hanford Site

9 2 1 2 4 5 2 1 6 0 3

4.3.3 Threatened and Endangered Species

Threatened and endangered plants and animals, as listed by both the federal government (DOI 1986; Dunn 1987[a]) and the State of Washington (Washington National Heritage Program 1987), are shown in Table 4.3-7. There are no plants or mammals on the federal list of Endangered and Threatened Wildlife and Plants (50 CFR 17.11, 17.12) that are known to occur on the Hanford Site. There are, however, several species of both plants and animals that are under consideration for formal listing.

TABLE 4.3-7. Threatened (T) and Endangered (E) Species

Common Name	Scientific Name	Federal	State
Plants			
Columbia milk-vetch	Astragalus columbianus		T
Yellowcress	Rorippa columbiae		E
Birds			
American peregrine falcon	Falco peregrinus	E	E
Bald eagle	Haliaeetus leucocephalus	T	T
White pelican	Pelecanus erythrorhychon		E
Sandhill crane	Grus canadensis		E
Ferruginous hawk	Buteo regalis		T
Mammals			
Pygmy rabbit	Slylvilagus idahoensis		T
Merriam's shrew	Sorex merriami		E
Pallid bat	Antrozous pallidus		E
Long-eared myotis	Myotis evotis		E

(a) A. Dunn, U.S. Department of the Interior, Fish and Wildlife Service Letter to E. B. Moore, Pacific Northwest Laboratory, September 10, 1987. Subject: Response to 1-3-87-SP-341, a list of endangered and threatened species.

Plants

Two species of plants are included in the State of Washington listing. Columbia milk-vetch (*Astragalus Columbianus* Barneby) is listed as threatened, and yellowcress (*Rorippa columbiae* Suksd.) is designated as endangered. Columbia milk-vetch occurs on dry land benches along the Columbia River in the vicinity of Priest Rapids Dam, Midway, and Vernita. Yellowcress occurs in the wetted zone of the water's edge along the Columbia River.

Birds

The federal government lists the American peregrine falcon (*Falco peregrinus anatum*) as endangered and the bald eagle (*Haliaeetus leucocephalus*) as threatened. The State of Washington lists, in addition to the peregrine falcon and bald eagle, the white pelican (*Pelecanus erythrorhynchos*) and sandhill crane (*Grus canadensis*) as endangered, and the ferruginous hawk (*Buteo regalis*) as threatened. The peregrine falcon is a casual migrant to the Hanford Site and does not nest here. The bald eagle is a regular winter resident where it forages on dead salmon and waterfowl along the Columbia River; it does not nest on the Hanford Site. Increased use of power poles for nesting sites by the ferruginous hawk has been noted. State of Washington Bald Eagle Protection Rules were issued in 1986 (WAC 232-12-292). These rules will require DOE to prepare a management plan to mitigate eagle disturbance, to obtain agreement from the State Game Department and may require specific buffer zones in line with U.S. Fish and Wildlife Service guidelines.

Mammals

The pygmy rabbit (*Sylvilagus idahoensis*) is considered threatened, and the Merriam's shrew (*Sortex merriami*), pallid bat (*Antrozous pallidus*), and long-eared myotis (*Myotis evotis*) are listed as endangered by the State of Washington. The pygmy rabbit is only known to occur on a small area of the ALE reserve.

4.3.4 Wildlife Refuges

Several national and state wildlife refuges are located on or adjacent to the Hanford Site. These refuges are shown in Figure 4.3-7.

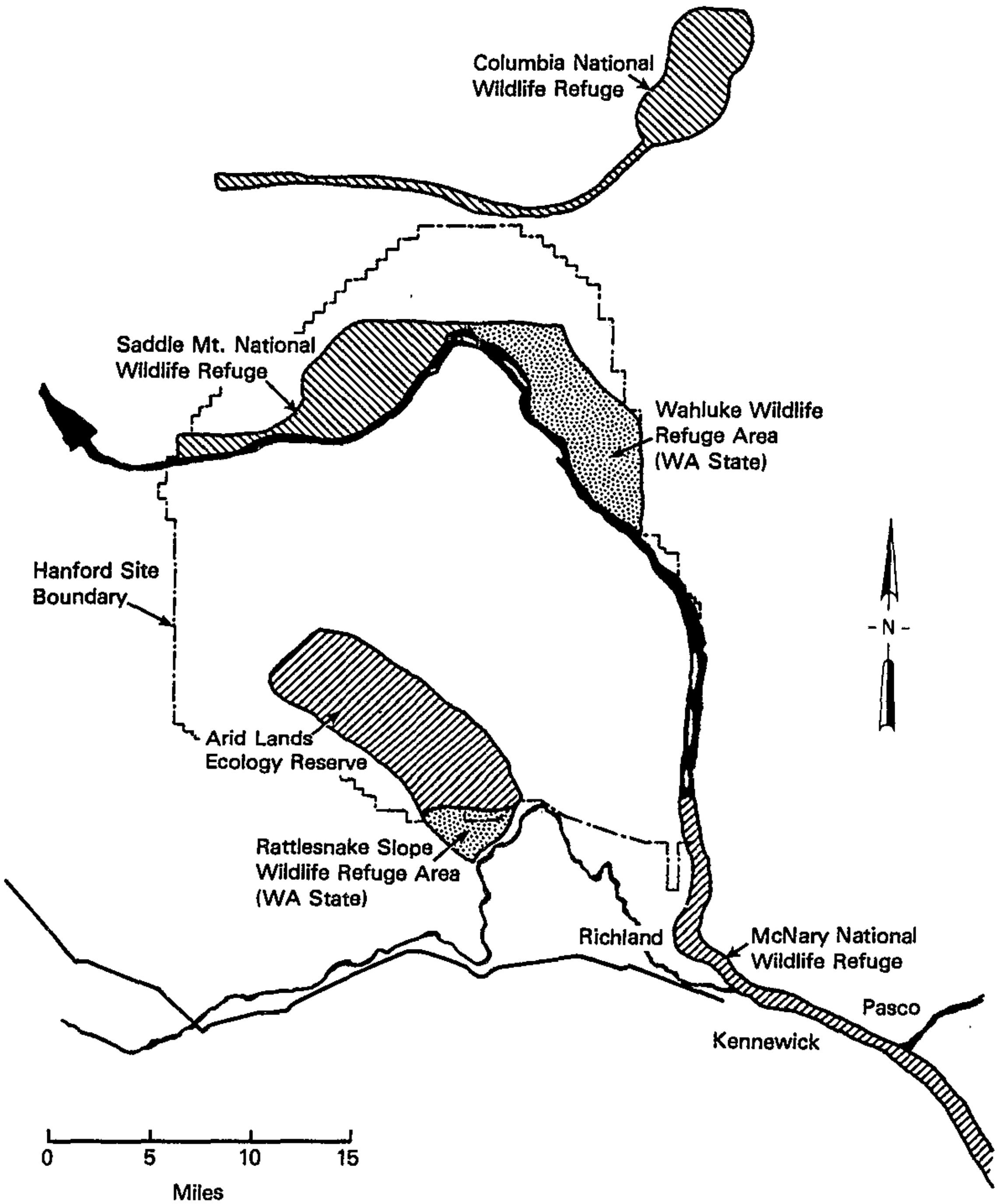

FIGURE 4.3-7. National and State Wildlife Refuges in the Vicinity of the Hanford Site

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4.3.5 100 Areas

For most purposes, the ecological characterization of the Hanford Site can be used. Some of the unique characteristics of the 100 Areas are presented below.

Terrestrial Ecology

Cheatgrass is prevalent because of the extensive perturbation of the soils in these areas. The characteristic communities found are cheatgrass-tumble mustard, sagebrush/cheatgrass or Sandberg's bluegrass, sagegrass-bitterbrush/cheatgrass, and willow-riparian vegetation near the Columbia River shoreline.

The insects, reptiles, amphibians, birds, and mammals found in this area are the same ones common for the Hanford Site with the following exceptions. California quail and Chinese ring-necked phesants are more likely to be found near the Columbia River, and several mammals, such as raccoons, beaver, and porcupines, are more likely to be present near water.

Aquatic Ecology

The major aquatic site related to the 100 Areas is, of course, the Columbia River, which flows past each of the reactor sites. The ecology of the Columbia River is presented in the Hanford Site section.

Threatened and Endangered Species

Two of the plants listed by the State of Washington occur in proximity to the Columbia River and could be found in the 100 Areas. They are the Columbia milk-vetch (Astragalus columbianus Barneby), listed as threatened, and yellowcress (Rorippa columbiae Suksd.) designated as endangered.

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4.3.6 <u>200 Areas</u>

The description of the ecological characteristics of the Hanford Site can be used for most work pertaining to the 200 Areas. Unique features are described below.

<u>Terrestrial Ecology</u>

Most of the plant commmunities occurring on the Hanford Site can be found near the 200 Areas, or at least on the 200-Area Plateau. The sagebrush/cheatgrass or Sandberg's bluegrass community is perhaps the most common in the area.

The insects, birds, reptiles, amphibians, and mammals common to the Hanford Site can be found in this area.

<u>Aquatic Ecology</u>

The aquatic sites found in the 200 Areas are the temporary water bodies described under the general Hanford Site section and are those associated with waste disposal practices. No other unique sites occur in this area.

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4.3.7 300 Area

There are no unique terrestrial or aquatic ecological characteristics to the 300 Area. It is most like the 100 Areas because of the proximity of the Columbia River.

The ant populations of the Hanford 300 area waste burial grounds were characterized by Fitzner et al. (1979). The species encountered were Solenopsis molesta, Pogonomyrmex owyheei, Formica subpolita, and Formica manni. The habits of each species are provided in Fitzner et al. (1979). Ants are of some concern in radioactive waste management since they can excavate soil to a depth of several meters. Buried waste can thus be transported from shallow waste burial sites to the surface.

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4.3.8 References

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4.4 HISTORICAL, ARCHAEOLOGICAL, AND CULTURAL RESOURCES

The Hanford Site is known to be rich in cultural resources. It contains numerous, well-preserved archaeological sites representing both the prehistoric and historical periods and is still thought of as the homeland of many Indian people.

4.4.1 Archaeological Resources

People have inhabited the Middle Columbia River region since the end of the glacial period. Over 10,000 years of prehistoric human activity in this largely arid environment have left extensive archaeological deposits along the river shores (Leonhardy and Rice 1970; Greengo 1982). Well-watered areas inland from the river also show evidence of concentrated human activity (Chatters 1982; Daugherty 1952; Greene 1975; Leonhardy and Rice 1970; Rice 1980). Graves are common in various settings and spirit quest monuments are still to be found on high, rocky summits of the mountains and buttes (Rice 1968a). Throughout most of the region, hydroelectric development, agricultural activities, and domestic and industrial construction have destroyed or covered over the majority of these deposits. Amateur artifact collectors have had an immeasurable impact on what remains. By virtue of their inclusion in the Hanford Site, from which the public is restricted, archaeological deposits found in the Hanford reach of the Columbia River and on adjacent plateaus and mountains have been spared some of the disturbances that have befallen other sites. The Hanford Area is thus a de facto reserve of archaeological information of the kind and quality that has been lost elsewhere in the region.

There are currently 133 prehistoric archaeological sites recorded in the files of the Washington State Office of Archaeology and Historic Preservation. Forty-seven of these sites are included on the National Register of Historic Places (National Register), two as single sites (45BN121, Hanford Island Site; 45GR137, Paris Site) and the remainder in seven archaeological districts (Table 4.4-1). In addition, nominations are being prepared for one archaeological site (45BN179, Hanford Generating Plant Site) and one archaeological district (Gable Mountain), and a second archaeological district is pending (Wahluke) (Table 4.4-2). Two other areas have been identified as localities with extensive low-density scatters of artifacts and other

TABLE 4.4-1. Historic Properties on the Hanford Site Listed on the National Register of Historic Places and the Archeological Sites Included in Them

Property	Sites
Wooded Island A.D.[a]	45BN107 through 112, 45BN168
Savage Island A.D.	45BN116 through 119, 45FR257 through 262
Hanford Island Site	45BN121
Hanford North A.D.	45BN124 through 134, 45BN178
Locke Island A.D.	45BN137 through 140, 45BN176 45GR302 through 305
Ryegrass A.D.	45BN149 through 157
Paris Site	45GR137
Rattlesnake Springs A.D.	45BN170, 45BN171
Snively Canyon A.D.	45BN172, 45BN173

(a) A.D. indicates archaeological district.

TABLE 4.4-2. Historic Properties on the Hanford Site Which Have Been Nominated to the National Register of Historic Places or for Which Nominations are Being Prepared

Property Name	Site(s) Included
Hanford Generating Plant Site[b]	45BN179
White Bluffs Townsite[a]	45FR314h
Gable Mountain/Gable Butte A.D.[b]	45BN332, 45BN348 through 352, 45BN354-363
Wahluke A.D.[a]	45BN141 through 147, 45GR306
Coyote Rapids A.D.[c]	45BN152, 45GR312 through 314

(a) Nomination is being prepared.
(b) Has been nominated, decision is pending.
(c) Nominated, rejected because of lack of documentation.

cultural remains. These are the shifting dunes locality, which lies between the 400 and 100-F Areas, and Gable Butte. Archaeological sites include numerous villages of pithouse remains, various types of open campsites and cemeteries along the river banks (Rice 1968a, 1980), spirit quest monuments (rock cairns), hunting camps and game drive complexes in mountains and rocky bluffs (Rice 1968b), and small temporary camps near perennial sources of water located away from the river (Rice 1968b).

Most recorded sites were found during four archaeological reconnaissance projects conducted between 1926 and 1968 (Krieger 1928; Drucker 1948, Rice 1968a, 1968b). Systematic Archaeological Surveys conducted in the late 1970s and early 1980s are responsible for the remainder (Cleveland et al. 1976; Rice 1981, 1987; Smith et al. 1977; Thoms et al. 1983). Little excavation has been conducted at any of the sites, and the Mid-Columbia Archaeological Society (MCAS) has done most of that work. They have conducted minor test excavations at several sites on the river banks and islands (Rice 1980) and a larger-scale test at site 45BN157 (Den Beste and Den Beste 1976). In addition, the University of Idaho excavated a portion of site 45BN179 (Rice 1980) and collaborated with the MCAS on its other work. The majority of the archaeological survey and reconnaissance activity has concentrated on islands and on a strip of land less than 400 m wide on either side of the river (Rice 1980). During his reconnaissance of the Hanford Site in 1968, Rice (1968b) inspected portions of Gable Mountain, Gable Butte, Snively Canyon, Rattlesnake Mountain, and Rattlesnake Springs but largely ignored other areas. Rice inspected additional portions of Gable Mountain and part of Gable Butte in the late 1980s (Rice 1987). Except for reconnaissance of the Basalt Waste Isolation Project Reference Repository Location (RRL; Rice 1984), reconnaissance of a proposed land exchange in T22N, R27 E, Section 33 (Rice 1981), surveys of three narrow transportation and utility corridors (ERTEC 1982; Morgan 1981; Smith et al. 1977), and a sample survey conducted for BWIP (Rice 1987), nonriverine areas have received little attention. Thus it is not surprising that only 15 of the 133 recorded sites occur more than 400 m from the river.

4.4.2 Native American Cultural Resources

In Prehistoric and early historic times, the Hanford reach of the Columbia River was heavily populated by Indian people of various tribal affiliations. Wanapums and Yakima people of the Chamnapum band dwelled along the Columbia River from south of Richland upstream to Vantage (Relander 1956; Spier 1939). Some of their descendants still live nearby and others have been incorporated into the Yakima and Umatilla Reservations. Palus people, who lived on the lower Snake River, joined the Wanapum and Chamnapum to fish the Hanford reach and soon inhabited the river's east bank (Relander 1956; Trafzer and Scheuerman 1986). Walla Walla and Umatilla people also made periodic visits to the area to fish. These people retain traditional secular and religious ties to the region, and there are many young and old alike who have knowledge of the ceremonies and lifeways of their aboriginal culture. The Washane religion, which had its start among the Wanapums, is still practiced by many people on the Yakima, Umatilla, Warm Springs, and Nez Perce reservations. Native plant and animal foods, some of which can be found on the Hanford Site, are used in the ceremonies performed by the Washane members. Certain landmarks, especially Rattlesnake Mountain, Gable Mountain, Gable Butte, Goose Egg Hill and various sites along the Columbia River are sacred to them. These people also consider the many cemeteries that are found along the river to be sacred.

4.4.3 Historic Resources

The first Euro-Americans who came into this region were Lewis and Clark, who traveled along the Columbia and Snake rivers during their 1803-1806 exploration of the Louisiana Territory. They were followed by fur trappers, who also passed through on their way to more productive lands up and down river and across the Columbia Basin. It was not until the 1860s that merchants set up stores, a freight depot, and the White Bluffs Ferry on the Hanford reach. Chinese miners began to work the gravel bars for gold. Cattle ranches opened in the 1880s and farmers soon followed. Several small, thriving towns grew up along the riverbanks in the early twentieth century, including Hanford, White Bluffs, and Ringold. Other ferries were established at Wahluke and Richmond. The towns and nearly all other structures were razed after the U.S. Government acquired the land for Hanford Nuclear Reservation in the early 1940s (ERTEC 1981; Rice 1980).

Eleven historic archaeological sites and eleven other historic localities have been recorded in published literature. Localities include the Allard Pumping Plant at Coyote Rapids, the Hanford Irrigation Ditch, the Hanford townsite, Wahluke Ferry, the White Bluffs townsite, the Richmond Ferry, Arrowsmith townsite, a cabin at East White Bluffs ferry landing, the White Bluffs road, the old Hanford high school, and the Cobblestone Warehouse at Riverland. Archaeological sites include the East White Bluffs townsite and associated ferry landings, and an assortment of trash scatters and dumps. This relative paucity of historic sites is more apparent than real. This is due to the focus of archaeological surveys on prehistoric remains to the extent that only one survey (ERTEC 1982) recorded any historic Euroamerican sites. ERTEC was also responsible for minor test excavations at some of the sites, including the Hanford townsite locality. In addition to the few recorded sites, there are numerous areas of gold mine tailings along the river bank and the remains of homesteads, ranches, gas wells, and abandoned Army installations scattered over the entire Hanford Site.

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4.4.4 100 Areas

Except for a portion of 100-N, the 100 Areas have not been surveyed for cultural resources. However, the proximity of numerous archaeological sites indicates that significant cultural resources may exist in the unsurveyed areas.

- 100-B and -C Areas. The 100-B Reactor is listed on the Historic American Engineering Records and is being considered for nomination to the National Register of Historic Places. Other cultural resources are rare in the vicinity of 100-B and -C Areas, at least based on the level of reconnaissance that has been done there. Only three sites can be identified from the literature (Rice 1968a, 1980). Site 45BN153 lies partially within the 100-B and -C Areas, and 45GR315 and the remains of the twentieth century town of Haven lie on the opposite bank of the Columbia River. Judging strictly from the artifacts Rice (1968a) observed on the surface, 45GR315 contains artifact deposits as old as 3500 to 4000 years B.P.

- 100-D and -DR Areas. These are located in a cultural resource-poor segment of the Columbia River, at least on the basis of reconnaissance-level surveys. Two archaeological sites lie within 2 km of the areas, both of them on the left (opposite) bank of the river. Sites 45GR307 and 308 are open campsites of unknown age (Rice 1968a). Neither has been considered to be eligible for the National Register of Historic Places, but no record exists of a formal evaluation of the sites having been completed. The townsite of twentieth century Wahluke, which was at the landing of a ferry of the same name, is also situated on the river's left bank. The mid-channel island off the 100-D and DR areas may be the one called Watklimpt by the Wanapum Indians (Relander 1956).

- 100-F Area. The 100-F Area is situated on a segment of the Columbia River that contains a multitude of cultural sites. According to Relander (1956), camp and villages of the Wanapum people extended from the Hanford townsite upstream to the White Bluffs townsite. Among those were the villages of Walwaltkh, Tohoke, and Tacht and the sites of Wyone and Y'yownow, which were fishing and fish processing locations, respectively. Tacht (meaning White Bluffs), was one of the principal sedentary villages of the Wanapum. There are nine prehistoric archaeological sites within 2 km of this area, including 45BN132, 45BN133, 45BN134, 45BN136, 45BN137, 45BN178, 45FR264, 45FR265, and 45FR266. They all are identified as open camps, except for 45BN134, which contains housepits. Site 45FR264 appears to contain artifact deposits extending back to at least 6000 years B.P. Sites 45BN132 through 134 and 45BN178 are included in the Hanford North Archaeological District, which is listed on the National Register of Historic Places.

The principal historic site in the vicinity is the East White Bluffs ferry landing and townsite (site 45FR314h), which has been nominated to the National Register of Historic Places. It is located on the east bank of the Columbia River and is coterminous with 45FR266. The site was the upriver terminus of shipping during the early and mid-nineteenth century. It was from this point that supplies for the trappers, traders, and miners were off-loaded and where commodities from the interior were transferred from pack trains and wagons to river boats. The first store and ferry of the mid-Columbia region were located there (ERTEC 1981). A log cabin, thought to have been a blacksmith shop in the mid-nineteenth century, still stands there.

- 100-H Area. This area is situated in what is probably the most culturally rich area on the Hanford Site, and since construction of the dams elsewhere in the Columbia River system, the most archaeologically rich area in the western Columbia Plateau. There are ten recorded archaeological sites within 2 km of the area, including 45BN138 through 141, 45GR302(a,b, and c) through 45GR305. These include two historic Wanapum cemeteries, six camps (one associated with a cemetery), and three housepit villages. The largest village, 45GR302a, contains over 60 housepits and numerous storage caches. It appears to have been occupied from 2,500 years ago to historic times (see Rice 1968). All of these sites are included in an archaeological district called Locke Island, which was known to the Wanapum Indians as *K'watch* (Relander 1956).

The only recognized historic site in the vicinity is the White Bluffs townsite. This settlement was founded in the twentieth century. It has not been evaluated for eligibility to the National Register of Historic Places.

- *100-K Area*. Events took place at this locality that may be of great significance to Indian people in the interior Northwest. It was here, in the mid-nineteenth century, that Smohalla, Prophet of the Wanapum people, held the first *washat*, the dance ceremony that has become central to the *Washane* or Dreamer religion (Relander 1956). As a result of Smohalla's personal abilities, the religion spread to many neighboring tribes, and is now practiced in some form by members of the Colville, Nez Perce, Umatilla, Warm Springs, and Yakima tribes. The site of this historic event was the right bank of the Columbia River at Moon, or Water Swirl Place, which we call Coyote Rapids. There is an archaeological site there, 45BN152, that is just north of the area perimeter. Three other sites, 45GR312, 45GR313, and 45GR314 are on the opposite bank of the river. Together these sites comprise the Coyote Rapids Archaeological District. This district was nominated to the National Register of Historic Places, but the nomination was rejected in 1976 due to insufficient information. Sites 45BN149, 150, and 151 (the Ryegrass Archaeological District) are located just downstream of the 100-K Area.

- *100-N Area*. The 100-N Area is situated on an archaeologically rich segment of the Columbia River's shore. Within 2 km of the area perimeter there are eight archaeological sites, including 45BN149, 150, 151, 179, and 180 on the south shore and 45GR309, 310, and 311 on the north shore. Four of these are either listed on or considered eligible for inclusion on the National Register of Historic Places. Sites 45BN149, 150, and 151, which include two pithouse villages and one cemetery, respectively, comprise the Ryegrass

Archaeological District. Site 45BN179 is currently being nominated as the Hanford Generating Plant Site.

In 1973, Rice (1980) conducted test excavations at 45BN179. During that excavation, which consisted of excavating two trenches and two smaller pits (32 m^2), he found evidence of habitation during four periods in prehistory. The earliest, undated occupation of the site occurred during the Vantage Phase of the local chronology (Swanson 1962; Nelson 1969), which dates to before 4500 B.P. (3000 B.C.). Small amounts of material, also undated, were attributable to the Frenchman Springs Phase (4500-2500 B.P. [3000 to 500 B.C.]). Above that were dense artifact deposits and remains of pithouses dating after 1862 B.P. (88 A.D.), which Rice attributed to the Cayuse Phase (2000 B.P. [50 B.C.] to historic times). Capping the sequence of deposits was debris left by Wanapum Indian people during their historic occupation of the site. No excavations have been conducted in the Ryegrass Archaeological District, so the site's scientific potential is unknown.

Extant knowledge about the archaeology of the 100-N Area is based largely on reconnaissance-level archaeological surveys (e.g., Rice 1968b, see also 1980), which do not purport to produce complete inventories of the areas covered. Only the vicinity of the Hanford Generating Plant has been surveyed intensively for archaeological resources (Rice 1980). Consequently, as-yet-undiscovered, archaeological properties might exist in the 100-N Area and its immediate vicinity and some of these could be eligible for inclusion on the National Register of Historic Places.

Three areas near 100-N are known to have been of some importance to the Wanapum. The knobs and kettles south and east of the area were called <u>Moolimooli</u>, which means Little Stacked Hills. Coyote Rapids, which is a short distance upstream, was called <u>Moon</u>, or Water Swirl Place. Gable Mountain (called <u>Nookshai</u> or Otter) and Gable Butte, which lie to the south of the river, are sacred mountains where youths would go on overnight vigils seeking guardian spirits (Relander 1956). Although no known sites of religious importance actually lie within the 100-N compound, sites and especially cemeteries that might later be found there may have cultural importance to Indian people.

The most common evidence of historic activity now found near the 100-N Area is gold mine tailings on river banks and archaeological sites where homesteads once stood. Few of these vestiges of the early years remain. The double-fenced compound of the 100-N Area has been cleared of cultural resource concerns.

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4.4.5 200 Areas

An archaeological survey has been conducted of all undeveloped portions of the 200-East Area, and a 50% random sample has been conducted of undeveloped portions of the 200-West Area. No archaeological sites or areas of Native American interest were found in either area and none are known to exist within 2 km of their boundaries. The only historic site is the old White Bluffs freight road (see Rice 1984) that crosses diagonally through the 200-West Area. It is not considered to be eligible for the National Register.

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4.4.6 300 Area

Archaeological surveys of the 300 Area have been confined to a narrow strip along the river's banks (Cleveland et al. 1976; Drucker 1948, Rice 1968a; Thoms et al. 1983). The only exception was an inspection of the right-of-way for a proposed toll bridge just south of the area boundary (Morgan 1981). Four archaeological sites are located partially within the 300 Area, 45BN29, 45BN105, 45BN106, and 45BN62. Ten other sites are within 2 km of the area perimeter including 45BN28, 45BN30, 45BN31, 45BN104, and 45BN163 located on the right bank of the Columbia River, 45FR42, 45FR164, and 45FR308 located on islands in the river, and 45FR20 and 45FR21 located on the left bank. None of the sites in Benton County are currently considered eligible for the National Register, but there is no record of any of them having been subjected to the formal evaluation process. Consequently there is no information on the ages of the sites and little on their prehistoric uses. Sites have, however, been characterized according to their surface characteristics. Three of the sites in Benton County are housepit villages, including 45BN105, which is reported to contain four or five housepits (Rice 1968a). The remaining Benton County sites are open camping/fishing stations (4) and shell middens (2). The sites in Franklin County are outside the Hanford Site boundaries. Remains of homesteads and irrigation facilities can be seen on the heavily disturbed river bank in and adjacent to this area, but these have not been systematically investigated and none are recorded as historic archaeological sites.

One locality important to the historic Wanapum Indians is located near the 300 Area. Sekema, a favorite place for taking salmon that had already spawned, was located some 10 km north of Richland (Relander 1956), which would place it 2 to 3 km north of the 300-Area boundary. However, because Relander's descriptions of geographic locations are only approximate, it is possible that Sekema corresponds to any or all of the Benton County (BN) archaeological sites listed above.

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4.4.7 400 Area

The majority of the 400 Area has been so disrupted by construction activities that archaeologists surveying the site in 1978 were able to find only 30 acres that were undisturbed (Rice, Stratton, and Lundeman 1978). They found no cultural resources in that small area. No sites are located within 2 km of the 400 Area.

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4.4.8 1100 Area

No cultural resources have been identified in or near the 1100 Area. However, there is no record of any surveys having been conducted, so any statement about the lack of cultural values would be premature. No mention is made by Relander (1956) of any location important to the Wanapum Indians.

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4.4.9 3000 Area

Archaeological surveys of the 3000 Area have been confined to a narrow strip along the river's banks (Cleveland et al. 1976; Drucker 1948; Rice 1968a; Thoms 1983). Twelve sites are within 2 km of the area perimeter including 45BN267 located inland, 45BN26, 27, 28, and 104 located on the west bank, 45BN43, 44, 101, 102, 103, and 192 located on an island, and 45FR308 located on the east bank. None of the above-listed Benton County sites have been determined eligible for the National Register. However, none of the individual sites have been evaluated. Thoms (1983) recommended that these sites and others in the Tri-Cities area should be incorporated into an archaeological district, but that nomination has not been made. Site types represented in Benton County include one housepit/occupation site, six open camp/fishing stations, three shell middens, and one possible butchering site.

No historic sites have been identified for this area, but it is possible that homesteads and remnants of the North Richland townsite might be found there.

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4.5 SOCIOECONOMICS

Activity on the Hanford Site plays a dominant role in the socioeconomics of the Tri-Cities and other parts of Benton and Franklin counties. The agricultural community also has a significant effect on the local economy. The economic influences of Hanford are significant, but Hanford impacts the social aspects of the community as well through its dependence on a technically oriented workforce. Any major changes in Hanford activity requiring an environmental impact statement will potentially most affect the Tri-Cities and other areas of Benton and Franklin counties. Detailed analyses of the socioeconomics are found in Scott et al. (1987) and Watson et al. (1984).

4.5.1 Employment and Income

Three major sectors have been the principal driving forces of the economy in the Tri-Cities since the early 1970s: 1) U.S. Department of Energy (DOE) and its contractors operating the Hanford Site, 2) Washington Public Power Supply System in its construction and operation of nuclear power plants, and 3) the agricultural community, including a substantial food processing component. With the exception of a minor amount of agricultural commodities sold to local area consumers, the goods and services produced by these sectors are exported outside the Tri-Cities. In addition to the direct employment and payrolls, these major sectors also support a sizeable number of jobs in the local economy through their procurement of equipment, supplies, and business services.

In addition to these three major employment sectors, three other components can be readily identified as contributors to the economic base of the Tri-Cities economy. The first of these, loosely termed "other major employers" includes three such employers: 1) Advanced Nuclear Fuels in North Richland, 2) Sandvik Special Metals in Kennewick, and 3) Boise-Cascade's Wallula corrugated paper mill. The second of the other components is tourism. The Tri-Cities area has increased its convention business substantially in recent years, in addition to business generated by pleasure travel. The final component in the economic base relates to the local purchasing power generated not from current employees but from retired former employees. Government transfer payments in the form of pension benefits constitute a significant proportion of total spendable income in the local economy.

Table 4.5-1 presents 1987 estimates of employment and income for the various components of the economic base mentioned above. Below we discuss each of the basic sectors and the derivation of these estimates in detail.

DOE Contractors (Hanford)

Hanford continues to dominate the local employment picture with over one-fifth of the total jobs in Benton and Franklin counties in 1986 (13,300 out of 63,300). Note that the figure at 13,300 represents only Hanford workers living in either Benton or Franklin counties or approximately 92% of the total workforce. Beyond Hanford's direct employment, Hanford's payroll impacts the Tri-Cities and state economy. These effects are further described in Section 4.5.2.

In fiscal year 1986 (October 1985 through September 1986), DOE and its contractors purchased approximately $50 million of goods and services in the Tri-Cities. For the study, it was assumed that a comparable amount of spending occurred over calendar year 1987. The leading categories of these purchases include office equipment, furniture, computers, small tools, and electrical supplies. The most recent study shows that total DOE procurement is estimated to have supported approximately 800 jobs in Benton and Franklin counties, the vast majority of these jobs falling into the wholesale and retail sector. In total, these jobs provided an additional $19 million in payroll to the economy, over and above that generated directly by DOE and contractor workers.

Washington Public Power Supply System

Although activity related to nuclear power construction ceased with the completion of the WNP-2 reactor in 1983, Washington Public Power Supply System continues as a major employer in the Tri-Cities area. Headquarters personnel based in Richland oversee the operation of two generating facilities and perform a variety of functions related to two mothballed nuclear plants. In the first half of 1988, Washington Public Power Supply System headquarters employment averaged slightly over 1,350 workers.

TABLE 4.5-1. Basic and Secondary Sectors, Benton and Franklin Counties, 1988

Basic	Employment	Payroll $ million
DOE and contractors (Hanford)	13,300[a]	460.0
Local procurement (direct employment)	800[b]	19.0
Washington Public Power Supply System and contractors	1,500	59.0
Agriculture	10,600	168.7
Proprietors	2,300[c]	67.9
Employees	4,600	42.0
Agri-Business	1,200[d]	13.8
Food Processing	2,500	45.0
Other Major employers	1,450[e]	58.3
Tourism	1,900	15.0[f]
Retirees	N/A	150.0[g]
Total Primary	29,550	930.0
Total Secondary	33,750	496.0
Total Employment	63,300	1,426.0

(a) Estimate for FY 1987. Eight percent of total employment used as a residence adjustment. This employment figure estimates the number of employees who are residents of Benton and Franklin counties.
(b) Estimated from procurement data and the 1982 input/output study of Washington.
(c) Proprietors' income for 1986, last year for which data is available from Regional Economic Information Service, U.S. Department of Commerce.
(d) Based on estimate made by local area labor economist, D. Schau, in April 1983.
(e) Boise Cascade's employment adjusted to include only workers living in the Tri-Cities area.
(f) Derived from an estimate by Washington State Department of Tourism, as published in Tri-City Herald, April 17 1987.
(g) Government pension benefits--federal civilian and military, state and local. Source: Regional Economic Information System, Bureau of Economic Analysis 1986.

Approximately 150 additional people worked for two major Washington Public Power Supply System contractors during 1986. Washington Public Power Supply System activities generated roughly a $59 million payroll in the Tri-Cities during the year.

Agriculture

Agricultural activities in Benton and Franklin counties are responsible for nearly 10,000 jobs, or nearly one-sixth of total employment. According to the U.S. Department of Commerce's Regional Economic Information System, there were about 2,300 people classified as farm proprietors in 1986. Farm proprietors' income from this same source was estimated to be $67.9 million in the same year.

Crop and livestock production in the two-county area generated about 4,600 wage and salary jobs, as represented by the employees covered by unemployment insurance. The presence of seasonal farm workers would make the total number of farm workers higher. Apart from the difficulty of obtaining reliable information on the number of seasonal workers, there is the question of how much of these earnings is actually spent in the local area. For this analysis we assumed that the impact of seasonal workers on the local economy is sufficiently small to be safely ignored.

The area's farms and ranches generate a sizeable number of jobs in supporting activities, such as agricultural services (e.g., application of pesticides and fertilizers, irrigation system development, etc.) and sales of farm supplies and equipment. These activities, often called "agri-business," employ 1,200 people. This figure has been reduced from the estimate of 1,350 jobs made in 1981 by Mr. Dean Schau of the Washington State Employment Security Department. Based on a somewhat depressed farm sector in 1987, as compared to 1981, this figure was reduced to 1,200. This component of agriculture generated roughly an $18 million payroll in the Tri-Cities area in 1987.

Although formally classified as a manufacturing activity, food processing is a natural extension of the farm sector discussed above. More than 20 food processors in Benton and Franklin counties produce such things as potato products, canned fruits and vegetables, wine, and animal feed.

Full-time employment in this sector averaged over 2,500 in 1987, with an estimated payroll of $45 million.

Other Major Employers

Other major employers--Advanced Nuclear Fuels, Sandvik Special Metals, and Boise-Cascade--generate about $58 million in payroll to Tri-Cities residents. Although Boise Cascade's Wallula mill lies outside both Benton and Franklin counties, the vast majority of its workforce resides in the Tri-Cities.

Tourism

In recent years, tourism activity has increased significantly in the Tri-Cities. In 1987, over 300 conventions or tournaments were held in the Tri-Cities, in which an estimated $19 million was spent by visitors. A study by the Washington State Department of Tourism estimated that overall tourism expenditures in the Tri-Cities were roughly $80 million in 1986. An adjustment to these figures was made to deduct the business travel associated with visitors on DOE business. This activity generated an estimated $15 million payroll and roughly 1,900 jobs in the local economy.

Retirees

Although the Benton and Franklin counties have a relatively young population (60% under the age of 35 as compared to a national average of 56%), over 13,000 people over the age of 65 reside in Benton and Franklin counties. In fact, the portion of the total population that is 65 years and older is currently increasing at a greater rate than is being experienced by Washington State. This segment of the population supports the local economy on the basis of income received from government transfer payments and pensions, private pension benefits, and prior individual savings.

Although information on private pensions and savings is not available, data are available regarding the magnitude of government transfer payments. The Department of Commerce's Regional Economic Information System has estimated transfer payments by various programs at the county level. A summary of estimated major government pension benefits received by the residents of Benton and Franklin counties in 1986 is shown in Table 4.5-2. The total

TABLE 4.5-2. Government Retirement Payments in Benton and Franklin Counties, 1986 (millions of dollars)

	Benton County	Franklin County	Total
Social Security (incl. survivors & disability)	70.4	23.9	94.3
Railroad retirement	1.8	2.8	4.6
Federal civilian retirement	7.7	2.2	9.9
Veterans pension and military retirement	11.7	3.3	15.0
State and local employee retirement	16.7	4.1	20.8
	$108.3	$36.3	$144.6

transfer payment income was about $150 million in 1987, which is calculated by extrapolating 1986 figures by the change in the Consumer Price Index between 1986 and 1987. About two-thirds of the Social Security payments go to retired workers; the remainder are for disability and other payments. The historical importance of government activity in the Tri-Cities area is reflected in the relative magnitude of the government employee pension benefits as compared to total payments. Federal, state, and local retirement benefits comprise 21% of the total benefits shown. On a national basis this percentage is smaller, approximately 18% (in 1984).

The Washington State Office of Financial Management estimated that there were 13,240 people 65 years or older living in Benton and Franklin counties in 1987. This estimate implies per capita transfer payments of $10,800. Of course, some of these payments are received by younger retirees. Adding in the population aged 60 to 64, this average is reduced to about $8,400, which may be a reasonable lower bound. Data for 1980 show that monthly social security benefits in Benton County were about 9% higher than the national average. In addition, the greater share of retirees receiving government employee pensions, as mentioned above, is also likely contributing to the higher per capita figure.

The discussion above may help to reveal that the purchasing power of senior citizens is an important component of the Tri-Cities economy just as for the entire nation. Taken as a whole, the estimated income of this component of the basic sector is roughly equivalent to the entire agricultural sector as seen in Table 4.5-1.

<u>Secondary Sector</u>

The secondary sector consists of all other workers in Benton and Franklin counties. The actual number is computed as the difference between total employment of Tri-Cities residents and the sum of basic sector employment as described above. In 1986, this difference resulted in an estimate of 33,750 workers in the secondary sector which dominated wholesale and retail trade with about 11,000 wage and salary workers.[a] Various services (excluding business services, mainly DOE contractor employment) employ about 6,000 people and local government employs around 8,000 workers. The remaining workers in the secondary sector are in transportation, communication, utilities, finance, real estate, and construction.

4.5.2 Hanford and the Local and State Economy

In 1987, Hanford employment accounts directly for 26% of total non-agricultural employment in Benton and Franklin counties and 0.8% of all statewide jobs. Hanford employs more Washingtonians than the entire primary aluminum industry and almost as many as the pulp and paper industry.

Hanford accounts for over two-thirds of Washington employment in chemicals and allied products, or about 4% of all Washington manufacturing jobs. Hanford Site operations directly account for an estimated 33% of the dollars earned in Benton and Franklin counties in 1986 and 1.1% of all dollars earned in Washington State industries.

Each of 14,450 total Hanford jobs supports about 1.2 additional jobs in the local service sector of Benton and Franklin counties (about 2.2 total

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(a) To some degree, wholesale and retail trade also contains a "basic" component, since the Tri-Cities serve as a regional trade center for an area reaching northward into Grant County and southward to Oregon. The extent of this basic activity is not known, but it results in an overstatement of the size of the secondary sector relative to the basic sector.

jobs) and about 1.5 additional jobs in the state's service sector (about 2.5 total jobs). Similarly, each dollar of Hanford income supports about 2.1 dollars of total local incomes and about 2.4 dollars of total statewide incomes. In Benton and Franklin counties, Hanford directly or indirectly accounts for over 50% of all jobs and 55% of all income.

Based on November 1, 1986, postal records, 92% of the direct employment and payroll of Hanford go to residents of the Benton and Franklin counties. Nearly 80% of the employment and payroll go to residents who reside in one of the Tri-Cities. Over 45% of the payroll and employment go to Richland residents, 27.7% to Kennewick residents, and 9.5% to Pasco residents. West Richland, Benton City, Prosser, and other areas in Benton and Franklin counties account for 11.5% of total employment and payroll.

Hanford and contractors spent nearly $154 million, or 47.5% of total procurements of $324 million, initially through Washington firms in 1986. About 18% of Hanford orders are filled by Tri-Cities firms. In many cases, these procurements filled by Tri-Cities firms only result in retail and wholesale markups; however, a significant portion of all Hanford orders, $6.6 million, are placed directly to Washington manufacturers.

Contractors spent $22 million on electricity and other utilities in 1986, ordered nearly $19 million in business services, and spent $73 million on Washington retail and wholesalers. Finally, DOE and its contractors provided about $16 million (mainly in grants) to local governments and others for a variety of public purposes.

Hanford contractors paid a total of $12.5 million in FY 1986 in state taxes on operations and purchases. Estimates show that Hanford employees paid $23.7 million in state sales and use taxes and $6.3 million in other taxes and fees in FY 1986. In addition, Hanford paid $2.3 million to local government in Benton, Franklin, and Yakima counties in sales and use taxes; $18.6 million in property taxes; and $1.2 million in other taxes in fees to county, city and special district governments. The grand total of taxes paid by Hanford to state and local governments was $65.5 million in FY 1986 (Scott et al. 1987).

4.5.3 Demography

Estimates by Washington State's Office of Financial Management, dated April 1988, place the Benton and Franklin counties' population totals at 104,000 and 35,300, respectively. These estimates compare with similar 1980 census data in which Benton County had 109,376 residents and Franklin County's population totalled 34,961. The year 1982 represents the period with the highest population: an estimated 111,700 residents in Benton County and 36,200 residents in Franklin County. There has been a subsequent decline relating to Washington Public Power Supply System work stoppage on nuclear plants WNP-1 and WNP-4.

Within each county, the 1988 estimates distribute the Tri-Cities population as follows: Richland, 30,140; Kennewick, 37,180; and Pasco, 18,430. The populations of Benton City, Prosser, and West Richland totaled 9,460 in 1987. Approximately 7,000 people live outside the Pasco city limits in the West Pasco/Riverview area.

The 1987 estimates of racial categories by the Bureau of the Census indicate that the overall Benton and Franklin counties' racial distribution generally reflects that of Washington State. County-wide, however, Benton and Franklin counties exhibit varying racial distributions as indicated by the calculations in Table 4.5-3.

The population estimates of Benton and Franklin counties show several factors that distinguish the population from Washington State's population. The population of Benton and Franklin counties is young with 50% of the total population under the age of 30 compared to 47% of the total state population. The largest age group in Benton and Franklin counties ranges from 25 to 29 years and represents 10% of the total population.

Estimates also show that the males represent more than 50% of the residents in Benton and Franklin counties. Males dominate the population from the 25-to-29-year age group through the 55-to-59 age group.

4.5.4 Housing

In 1988, nearly 88% of all housing (of 38,337 total units) in the Tri-Cities was occupied. Single-unit housing, which represents nearly 57% of the total units, has an average 93% occupancy rate throughout the Tri-Cities.

TABLE 4.5-3. 1987 Population Estimates by Bureau of the Census Racial Categories and for Spanish Origin

	Total	White	Black	Indian	Asian	Other Race[a]	Spanish Origin[b]
Washington State	4,481,100	4,020,103	123,131	68,230	147,961	121,675	159,504
Benton and Franklin Counties	139,600	129,618 93%[c]	2,257 2%	959 .7%	3,087 2%	4,856 3.5%	9,269
Benton County	104,100	99,452 96%	781 .8%	722 .7%	1,393 1%	1,752 2%	3,629
Franklin County	35,500	30,229 85%	1,476 4%	237 .7%	454 1%	3,104 9%	6,359

(a) The Other racial category is primarily a count of persons who marked "Other Race" on the 1980 census questionnaire and wrote in entries such as Cuban, Puerto Rican, Latino, Mexican, Dominican, etc. They represent persons who given an opportunity to identify themselves in a racial category did not select white (or any other category provided), but specifically identified themselves as being Mexican, Puerto Rican, Latino, etc. In 1980, this category represented a tabulation of 76,154 Spanish persons who considered themselves racially Spanish and some 9,402 additional responses that could not be elsewhere classified.

(b) Spanish Origin is not a race category; it may be viewed as a nationality group. Persons of Spanish Origin may be of any race and are counted in the other racial categories shown. In 1980, 44.4% of the persons who indicated they were of Spanish Origin identified themselves as being racially white; 47.6% selected the Other Races category. Very small percentages identified themselves as being black (1.3%), Indian (2.3%), or Asian (4.4%).

(c) Percentage figures refer to county, not state, populations.

Multi-unit housing, defined as housing with two or more units, has an occupancy rate of nearly 81%. Pasco has the lowest occupancy rate in all categories of housing: single-unit, 93%; multi-unit, 78%; and mobile homes and trailers, 84%. The mobile homes occupancy rate, however, is the only rate that is significantly lower than that of the other cities. Table 4.5-4 shows a detailed listing of total units and occupancy rate by type in the Tri-Cities.

4.5.5 Transportation

The Tri-Cities serve as a regional transportation and distribution center with major air, land, and river connections. The Tri-Cities has direct rail service, provided by Burlington Northern and Union Pacific, connecting the area to more than 35 states. Union Pacific operates the largest fleet of refrigerated rail cars in the Unites States and is essential to food processors that ship frozen food from this area. Passenger rail service is provided by Amtrak, which has a station in Pasco.

Docking facilities at the Ports of Benton, Kennewick, and Pasco are important aspects of this region's infrastructure. These facilities are located on the 325-mile-long commercial waterway, made up of the Snake and Columbia rivers, extending from the Ports of Lewiston-Clarkston in Idaho to the deep-water ports of Portland, Oregon and Vancouver, Washington. The average shipping time from the Tri-Cities to these deep water ports by barge is 36 hours (Evergreen Community Development Association 1986).

TABLE 4.5-4. Total Units and Occupancy Rates (April 1988 Estimates)

	All Units		Single Units		Multi-Units		Mobile Homes/ Trailers	
	Total	Rate, %	Total	Rate, %	Total	Rate, %	Total	Rate, %
Richland	13,850	89	8,737	95	4,665	78	456	95
Pasco	8,052	86	3,990	93	3,069	78	1,993	84
Kennewick	16,427	90	9,130	92	5,867	84	1,430	90
Tri-Cities Average	38,337	89	21,857	93	13,601	81	2,879	91

Source: Personal communication with F. D'Allesandro, Analyst, Washington State Office of Financial Management, 8/18/88.

Daily air passenger and freight services connect the area with most major cities through the Tri-Cities Airport, located in Pasco. The airport is currently served by two commuter-regional and two national airlines. The main runway is 7,700 ft in length and can accommodate landings and takeoffs by medium-range commercial aircraft, such as the Boeing 727-200 and Douglas DC-9. The Tri-Cities airport currently handles about 145,000 passengers per year. Projections indicate that the recently expanded terminal can serve almost 250,000 passengers annually. Two additional airports, located in Richland and Kennewick, are limited to serving private aircraft.

The Tri-Cities are linked to the region by five major roads. Route 395 joins the area with Spokane to the northeast. Both it and route 240, which crosses through the Hanford Site, connect with Interstate 90 to the north. Route 12 links the region with Yakima to the northwest; Lewiston, Idaho to the east; Walla Walla to the southeast. Finally, the area is linked to Interstate 80 to the south, via routes 82 and 14. Routes 240 and 24 traverse the Hanford Site and are maintained by the State of Washington. Other roads within the reservation are maintained by the DOE.

4.5.6 <u>Public and Community Services</u>

<u>Education</u>

<u>Primary and Secondary</u>. Primary and secondary education are served by the Richland, Kennewick, Pasco, Burbank, and Kiona-Benton school districts. The combined 1987 spring enrollment for all three districts was approximately 26,000 students. This total consists of 10,000 students from the Kennewick school district, and about 1,200 and 800 students, respectively, in the Kiona-Benton and Burbank school districts. In 1987, the Kennewick and Pasco school districts were operating near or at their capacity. This is not the case with the Richland District, where enrollment peaked at 8,700 in the early-1980s. By opening schools that closed in the last several years, the Richland School District could expand enrollment by about 30%. In 1987, Kiona-Benton and Burbank districts were operating at about two-thirds capacity.

<u>Post Secondary</u>. Post-secondary education in the Tri-Cities area is provided by a junior college, Columbia Basin College, and by the Tri-Cities

University Center (TUC). TUC offers a variety of upper-division, undergraduate and graduate degree programs. In 1988, enrollment at these two institutions is approximately 7,000 students, with a capacity for about 10,000 students. Many of the programs offered by these two institutions are geared toward the vocational and technical needs of the area. Currently eight undergraduate and fourteen graduate programs are available.

4.5.7 Health Care and Human Services

The Tri-Cities have three major hospitals and four minor emergency centers. All three hospitals offer general medical services and include a 24-hour emergency room, basic surgical services, intensive care and neo-natal care.

Kadlec Medical Center, located in Richland, has 136 beds and runs at 50% capacity. The 6,000 annual admissions represent 47 to 48% of the Tri-Cities market, and 70%, or 4,200 of these admissions are non-Medicare/Medicaid. Non-Medicare/Medicaid patients average 3.2 days per admission.

Kennewick General Hospital maintains a 50% occupancy rate of its 71 beds with its annual 3,900 admissions. Approximately 70% of Kennewick General's admissions are from Kennewick and 5% are from Richland. As in Kadlec Hospital, non-medicare/Medicaid patients average 3.2 days per admission.

Our Lady of Lourdes, located in Pasco, faces a decreasing occupancy rate of 27%; however, the hospital performs a significant amount of out-patient care, and this income serves as the primary source of income for the hospital. In 1986, Our Lady of Lourdes had 3,000 admissions of which a full 50% were non-Medicare/Medicaid patients. Each admission stayed an average of 3.2 days.

Human Services

The Tri-Cities offer a broad range of social services. State human service offices in the Tri-Cities include the Job Services office of the Employment Security Department, Food Stamp offices, the Division of Developmental Disabilities, Financial and Medical Assistance, the Child Protective Service, emergency medical service, a senior companion program, and vocational rehabilitation.

The Tri-Cities are also served by a large number of private agencies and voluntary human services organizations. The United Way, an umbrella fund-raising organization, contributed $1.4 million in 1986 to its member agencies throughout the area. These member agencies had a cumulative budget total of $13.7 million in 1986 (United Way 1986). Some of the member agencies include: Association for Retired Citizens, Chaplaincy, Developmental Center, Food Bank, Lutheran Social Services, Mental Health Center, Rape Relief, Red Cross, Salvation Army, and A Woman's Place. A short listing of examples of human services facilities and organizations in the Tri-Cities follows on Table 4.5-5.

4.5.8 Police and Fire Protection

Police protection in Benton and Franklin counties is provided by Benton and Franklin counties' sheriff departments, local municipal police departments, local municipal fire departments, and the Washington State Patrol Division headquartered in Kennewick.

Table 4.5-6 shows the number of commissioned officers and patrol cars in each department. The Kennewick, Richland, and Pasco municipal departments maintain the largest staffs of commissioned officers with 48, 40, and 38, respectively. Table 4.5-7 indicates the number of fire-fighting personnel, paid and volunteer on the staffs of fire districts in the area.

By comparing violent crimes (homicide, rape, robbery, and aggravated assault) and property crimes (burglary, larceny-theft, motor vehicle theft, and arson) to the population for 1987, differences are revealed in the crime rate between Benton and Franklin counties and each city, as measured by crimes per 1,000 residents. In Benton County, violent crimes occur at a rate of 2.6 per year per 1,000 residents and property crimes at 59.4 per year per 1,000 residents. Table 4.5-8 illustrates that both violent and property crimes in Richland occur at a lesser rate than in Kennewick. Pasco violent crime and property crime rates are the highest of the Tri-Cities at 10.2 per 1,000 residents and 129.9 per 1,000 residents, respectively.

The overall violent crime and property crime rates are slightly higher in Franklin County and lower in Benton County. The Benton County's violent

TABLE 4.5-5. Examples of Human Services Facilities and Organizations in the Tri- Cities

Facility or Organization	Descriptive Comments
Benton-Franklin Association for Retarded Citizens	Provides counseling, recreation, transportation and referral services for learning-disabled individuals
Benton-Franklin Developmental Center	Provides services and programs for developmentally disadvantaged children.
Catholic Family Services Lutheran Social Services of Washington	Provides foster care programs, family and individual counseling programs and adoptive services.
Children's Home Society of Washington	Provides residential treatment facilities and program for emotionally disturbed children.
Columbia Industries	Assists the physically and mentally disabled toward meaningful employment through vocational evaluation, work training, job placement and sheltered employment.
Benton-Franklin Council on Aging	Provides meals, household assistance, health care, information and transportation services.
Evergreen Legal Services	Provides free legal aid program for civil cases involving low-income persons.
Good Shepherd Home	Provides a residential treatment program for adolescent girls with behavior problems.
A Woman's Place	Provides crisis phone counseling and temporary residence for women and their children who are victims of domestic violence.
Planned Parenthood of Benton-Franklin Counties	Provides family planning education, information and assistance programs.
Tri-Cities Chaplaincy	Provides chaplaincy service to those with life-threatening illnesses and their families, including a hospice program.
Tri-Cities Food Bank	Provides food for those in need.

Source: Watson et al. 1984.

TABLE 4.5-6. Police Personnel in Tri-Cities, 1988

	Commissioned Officers	Patrol Cars
Benton City Municipal	4	3
Kennewick Municipal	48	13
Pasco Municipal	38	13
Richland Municipal	40	10
West Richland Municipal	7	4
County Sheriff, Benton County	31	27
County Sheriff, Franklin County	14	12

Source: Personal communication with each department office, August 1988.

TABLE 4.5-7. Fire Protection in Tri-Cities, 1988

	Fire Fighting Personnel	Volunteers	Total	Service Area
Kennewick	39	0	10	City of Kennewick
Pasco	21	0	26	City of Pasco
Richland	38	0	38	City of Richland
BCRFD 1	5	100	105	Kennewick Area
BCRFD 2	0	21	21	Benton City
BCRFD 4	2	28	30	West Richland

Source: Personal communication with each department office, August 1988.

TABLE 4.5-8. Violent and Property Crimes

	Violent Crimes per 1,000 Residents	Property Crimes per 1,000 Residents
Benton County	2.6	59.4
Richland	1.2	49.1
Kennewick	2.5	93.3
Franklin County	6.1	81.6
Pasco	10.2	129.9
Yakima County	4.7	81.6
Spokane County	3.6	64.4
Washington State	4.5	67.0

crime rate per 1,000 residents is slightly below those of Washington State, while Franklin County's rate exceeds the Washington State rates.

4.5.9 Parks and Recreation

The convergence of the Columbia, Snake, and Yakima rivers offers the residents of the Tri-Cities a variety of recreational opportunities.

The Lower Snake River Project includes Ice Harbor Lower Monumental, Little Goose, Lower Granite locks and dams, and a levee system and parkway at Clarkston and Lewiston. While navigation capabilities and the electrical output represent the major benefits of this project, recreational benefits have also resulted. The Lower Snake River Project provides boating, camping, and picnicking facilities in nearly a dozen different areas along the Snake River. In 1986, nearly 385,000 people visited the area and participated in activities along the river.

Similarly, the Columbia River provides ample water recreational opportunities on the lakes formed by the dams. Lake Wallula, formed by McNary Dam, offers a large variety of parks and activities, which attracted over 3 million visitors in 1986. The Columbia River Basin is also a popular area for migratory waterfowl and upland game bird hunting.

Other opportunities for recreational activities in the Tri-Cities are accommodated by the indoor and outdoor facilities available, as described in Table 4.5-9. Numerous tennis courts, ball fields, and golf courses offer

TABLE 4.5-9. Examples of Physical Recreational Facilities Available in the Tri-Cities

	Facilities
Tennis	62 outdoor courts (e.g., Sylvester Park, Howard Amon Park, Pasco High School). Indoor courts at Tri-City Court Club and the Columbia Basin Racquet Club.
Golf	Six courses including Tri-City Country Club, Canyon Lakes and West Richland Municipal Golf Course. Several driving ranges and pro shops are also available.
Bowling	Lanes in each city including Atomic Bowling Center, Clover Leaf Lanes and Columbia Lanes.
Swimming	Private (e.g., Ranchette Estates, Oasis Water Park) and public (e.g., Richland, Pasco, Kennewick) swimming pools in the area. Boating, water-skiing and swimming on the Columbia River in the Tri-Cities area.
Ball	Baseball fields and basketball courts are located throughout the Tri-Cities including Badger Canyon, Craighill Playgrounds, Stevens Playground and Lewis and Clark School. Soccer and football fields are also located in various areas.
Skating	Roller-skating and skateboard facilities.
Camping	Several hundred campsites within driving distance from the Tri-Cities area including Levy Park, Fishhook Park and Sun Lakes.
Fishing	Steelhead, sturgeon, trout, walleye, bass and crappie fishing in the lakes and rivers near the Tri-Cities area.
Hunting	Duck, geese, pheasant and quail hunting. Deer and elk hunting in the Blue Mountains and the Cascade Range.

Source: Watson et al. (1984).

outdoor recreation to residents and tourists. Several privately owned health clubs in the area offer indoor tennis and racquetball courts, pools, and exercise equipment. Bowling lanes and roller skating rinks also serve each of the Tri-Cities.

4.5.10 Utilities

Water

The principal source of water in the Tri-Cities is the Columbia River from which the water systems of Richland, Pasco, and Kennewick draw a large portion of the average 32.7 million ft^3 necessary each day. Each city operates its own supply and treatment system.

The Richland water supply system derives 90% of its water from the Columbia River and the remaining 10% from ground-water wells. The city of Richland's total usage in 1986 was 583.6 million ft^3; residential, 328 million ft^3; industrial and commercial, 197.1 million ft^3; parks, 3.5 million ft^3; government and schools, 54.5 million ft^3. This current usage represents approximately 40% of the maximum supply capacity. The city of Pasco system likewise draws from the Columbia River for its water needs. The 1986 estimates of production fall at 267.4 million ft^3. The Kennewick system uses two wells to supplement its supply provided by the Columbia River. These wells serve as the sole source of water between November and March and can provide approximately 60% of the total maximum supply of 850 million ft^3. The 1986 usage was billed at 344 million ft^3 and represents approximately 40% of maximum supply capacity.

The major incorporated areas of Benton and Franklin counties are served by municipal waste-water treatment systems, whereas the unincorporated areas are served by onsite septic systems. Richland's waste-water treatment system is designed to treat a total capacity of 975 million ft^3/yr. Recently constructed, the system currently processes more than 341 million ft^3/yr. The Kennewick system, similarly, has significant excess capacity. With a treatment capability of 424 million ft^3/yr, current usage is just over 50% at 224 million ft^3 annually. Pasco's waste-treatment system processes over 97 million ft^3 each year while the system could treat 207 million ft^3.

Electricity

Electricity in the Tri-Cities area is provided by the Benton County Public Utility District, Benton Rural Electrical Association, Franklin County Public Utility District, and City of Richland Energy Services Department. All of the power that these utilities provide in the local area is purchased from the Bonneville Power Agency (BPA), a federal power marketing agency. The average rate for residential customers served by the three local utilities is roughly 3.5 cents per kilowatt hour.

The Columbia River Basin's hydroelectric system extends throughout the region on the Snake and Columbia rivers and is the nation's most productive source of hydropower, with a combined potential of 23,000 megawatts of power.

The Ice Harbor Dam, near Pasco, is one of 19 dams that make up the Columbia River Basin's hydroelectric system. This system extends 596 miles from the Columbia's mouth to Grand Coulee Dam and 273 miles up the Snake River to the Brownlee Dam (Northwest Power Planning Council 1986).

4.5.11 Land Use

The Hanford Site encompasses 1,450 km^2 and includes several DOE operational areas. The major areas are as follows:

- The entire Hanford Site has been designated a National Environmental Research Park (NERP).
- The 100 Areas, bordering on the right bank (south shore) of the Columbia River, are the sites of the eight retired plutonium production reactors and the N Reactor is being modified for restart. The 100 Areas occupy about 11 km^2.
- The 200-W and 200-E Areas are located on a plateau about 8 and 11 km, respectively, from the Columbia River. These areas have been dedicated for some time to fuel reprocessing and waste processing management and disposal activities. The 200 Areas cover about 16 km^2.
- The 300 Area, located just north of the City of Richland, is the site of nuclear research and development and nuclear fuel fabrication. This area covers 1.5 km^2.
- The 400 Area is about 8 km north of the 300 Area and is the site of the Fast Flux Test Facility used in the testing of breeder reactor systems. Also included in this area is the Fuels and Material Examination Facility.

- The 600 Area includes all of the Hanford Site not occupied by the 100, 200, 300, or 400 Areas. Land uses within the 600 Area include:

  1. The Arid Land Ecology Reserve, a 310 km^2 tract set aside for ecological studies.
  2. The state of Washington leases 4 km^2, part of which is used for low-level radioactive waste disposal.
  3. 4.4 km^2 for Washington Public Power Supply System nuclear power plants.
  4. 2.6 km^2 transferred to the state of Washington as a potential site for the disposal of nonradioactive hazardous wastes.
  5. About 130 km^2 under revocable use permit to U.S. Fish and Wildlife Refuge.
  6. 225 km^2 under revocable use permit to the Washington State Department of Game for recreational game management.
  7. Support facilities for the controlled access areas.
  8. Near Surface Test Facility in Gable Mountain. This facility is part of the Basalt Waste Isolation Project (BWIP) to assess the feasibility of radioactive waste disposal in basalt formations.
  9. 46.7 km^2 for the Reference Repository Location (RRL) for the BWIP. This site includes all of the 200-West Area. The site of the principal borehole and exploratory shaft for the BWIP covers about 1 km^2 and is located just west of the 200-West Area within the reference repository site.

Surrounding the Hanford Site, 660 km^2 have been designated for ALE Reserve, U.S. Fish and Wildlife Refuge, and Washington State Department of Game (DOE 1986).

Land use in other areas includes urban and industrial development, irrigated and dry-land farming, and grazing. In 1985, wheat represented the largest single crop in terms of acreage planted in Benton and Franklin counties with 287,000 acres. Corn, alfalfa, hay, and barley are other major crops in Benton and Franklin counties.

In 1986, the Columbia Basin Project, a major irrigation project to the north of the Tri-Cities, produced gross crop returns of $343 million, representing 19% of all crops grown in Washington State. In 1986, the average gross crop value per irrigated acre was $664.00. The largest percentage of irrigated acres produced: alfalfa hay, 29.4% of irrigated acres; wheat, 15.0%, corn (feed grain), 9.4%. Other significant crops are potatoes, apples, dry beans, asparagus, and pea seed.

4.5.12 Offsite Historical and Cultural Sites

Currently, 16 archeological properties are located near the Hanford Site. These properties are listed in the National Register of Historic Places. Table 4.5-10 lists the historic places in counties adjacent to the Hanford Site.

TABLE 4.5-10. Washington State Register of Historic Places in Benton and Franklin Counties

Benton County
Benton County Courthouse, Prosser
Glade Creek Site, Prosser vicinity
Telegraph Island Petroglyphs, Paterson vicinity
Charles Conway House, Kennewick

Franklin County
Ainsworth, Pasco vicinity
Allen Rockshelter, Pasco vicinity
Burr Cave, Walker vicinity
Franklin County Courthouse, Pasco
Marmes Rockshelter, Lyons Ferry vicinity
James Moore House, Pasco
Palouse Canyon Archaeological District, Lower Palouse River vicinity
Pasco Carnegie Library, Pasco
Strawberry Island Village, Pasco vicinity
Tri-Cities Archaeological District, Pasco vicinity
Windust Caves Archaeological District, Ice Harbor Reservoir, Snake River

Source: Watson et al. (1984).

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4.5.13 References

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4.6 NOISE

Noise is technically defined as sound waves perceptible to the human ear. Sound waves are characterized by frequency, measured in Hertz (Hz), and sound pressure expressed as decibels (dB). Humans have a perceptible hearing range of 31 to 10,000 Hz. For regulatory purposes, noise levels for perceptible frequencies are weighted to provide an A-weighted sound level (dBA). The decibel is a value equal to 10 times the logarithm of the ratio of a sound pressure squared to a standard reference sound pressure level (20 micropascals) squared. The threshold of audibility ranges from about 60 dB at a frequency of 31 Hz to about less than 1 dB between 900 to 8000 Hz. For regulatory purposes, noise levels for perceptible frequencies are weighted to provide an A-weighted sound level (dBA). Sound pressure levels outside the range of human hearing are not considered noise in a regulatory sense, even though wildlife may be able to hear at these frequencies.

Noise levels are often reported as the equivalent sound level (Leq). The Leq is expressed in A-weighted (dBA) over a specified period of time, usually 1 or 24 hours. The Leq expresses time-varying noise levels by integrating noise levels over time and expressing them at a steady-state continuous sound level.

4.6.1 Background Information

Studies at Hanford dealing with the propagation of noise have dealt primarily with occupation noise at work sites. Environmental noise levels have not been extensively evaluated because of the remoteness of most Hanford activities and isolation from receptors that are covered by federal or state statutes. This discussion will focus on what little environmental noise data is available. The majority of available information consists of model predictions, which in many cases has not been verified because the predictions indicated that the potential to violate state or federal standards is remote or unrealistic.

4.6.2 Environmental Noise Regulations

The Noise Control Act of 1972 and its subsequent amendments (Quite Communities Act of 1978, 42 USC 4901-4918, 40 CFR 201-211) directs the regulation of environmental noise to the state. The state of Washington has adopted RCW 70.107 that authorizes the Department of Ecology to implement rules consistent with federal noise control legislation. RCW 70.107 and the implementing regulations embodied in WAC 173-60 through 173-70 defined the regulation of environmental noise levels. Maximum noise levels are defined for the zoning of the area for environmental designation for noise abatement (EDNA). The Hanford Site is classified as a Class C EDNA on the basis of industrial activities. Unoccupied areas are also classified as Class C areas by default because they are neither Class A (residential) or Class B (commercial). Maximum noise levels are established based on the classification (EDNA) of the receiving area and the source area (Table 4.6-1).

4.6.3 Hanford Site Sound Levels

Most industrial facilities on the Hanford Site are located far enough away from the Site boundary that noise levels at the boundary are not measurable or are barely distinguishable from background noise levels. Modeling of environmental noises has been performed for commercial reactors and State Highway 240 through the Hanford Site. These data do not deal with background levels of noise and are not reviewed here. There are two sources of measured environmental noise at Hanford. Environmental noise measurements were made in 1981 during Site characterization of the Skagit/Hanford Nuclear Power Plant Site (NRC 1986). The Hanford site was considered as the site for a geologic waste repository (BWIP) for spent commercial nuclear fuel and other high-level nuclear waste. Site characterization studies performed in 1987 included measurement of background environmental noise levels at five sites on the Hanford reservation.[a]

Skagit/Hanford Data

Preconstruction measurements of environmental noise were taken in June of 1982 on the Hanford Site. Fifteen sites were monitored and noise levels ranged from 30 to 60.5 dBA (Leq). The values for isolated areas ranged from

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(a) Coleman, S. R. 1988. Environmental Noise Monitoring, BWIP Site, Characterization Project. Letter Report CO-12023 to D. D. Dauble, Pacific Northwest Laboratory, Richland, Washington, February 18, 1988.

30 to 38.8 dBA. Measurements taken around the sites where the Supply System was constructing nuclear power plants (WNP-1,2, and 4) ranged from 50.6 to 64 dBA. Measurements taken along the Columbia River near the intake structures for WNP 2 were 47.7 and 52.1 dBA compared to more remote river noise levels of 45.9 dBA (measured about 3 miles upstream of the intake structures). Community noise levels in North Richland (3000 Area at Horn Rapids road and the By-pass Highway) were 60.5 dBA.

BWIP Data

Background noise levels were determined at five sites located within the Hanford Site. Noise levels are expressed as equivalent sound levels for 24 hours (Leq-24). Sample location, date, and Leq-24 are listed in Table 4.6-2. Wind was identified as the primary contributor to background noise levels with winds exceeding 12 mph significantly affecting noise levels. Coleman concludes that background noise levels in undeveloped areas at Hanford can best be describes as a mean Leq-24 of 24 to 36 dBA. Periods of high wind, which normally occur in the spring, would elevate background noise levels.[a]

TABLE 4.6-1. Applicable State Noise Limitations for the Hanford Site Based on Source and Receptor EDNA Designation (values are dBA)

Source Hanford Site	Receptor Class A Residential	Class B Commercial	Class C Industrial
Class C - Day	60	65	70
Night	50	--	--

(a) Coleman, S. R. 1988. Environmental Noise Monitoring, BWIP Site Characterization Project. Letter Report CO-12023 to D. D. Dauble, Pacific Northwest Laboratory, Richland, Washington, February 18, 1988.

TABLE 4.6-2. Background Noise Levels Measure At Isolated Areas

Site	Location			Date	Leq-24 (dBA)
	Sec.	Range	Township		
1	9	R25E	T12N	07-10-87	41.7
				07-11-87	40.7
				07-12-87	36.0
				07-13-87	37.2
				07-14-87	35.6
2	26	R25E	T13N	07-25-87	43.9
				07-26-87	38.8
				07-27-87	43.8
				07-28-87	37.7
				07-29-87	43.2
3	18	R26E	T12N	08-08-87	39.0
				08-09-87	35.4
				08-10-87	51.4*
				08-11-87	56.7*
				08-12-87	36.0
4	34	R27E	T11N	09-09-87	35.2
				09-10-87	34.8
				09-11-87	36.0
				09-12-87	33.2
				09-13-87	37.3
5	14	R28E	T11N	10-15-87	40.8
				10-16-87	36.8
				10-17-87	33.7
				10-18-87	31.3
				10-19-88	35.9

*Leq includes grader noise.

4.6.4 Reference

U.S. Nuclear Regulatory Commission (NRC). 1986. Draft Environmental Statement Related to the Construction of Skagit/Hanford Nuclear Project, Units 1 and 2. Prepared by Puget Sound Power & Light Company, Pacific Power and Light Company, the Washington Water Power Company, and Portland General Electric Company. NUREG-0894, U.S. Nuclear Regulatory Commission, Washington, D.C.

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HANFORD SITE NATIONAL ENVIRONMENTAL POLICY ACT (NEPA) CHARACTERIZATION

Chapter 5: Models Used to Estimate Environmental Impacts

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5.0 MODELS USED TO ESTIMATE ENVIRONMENTAL IMPACTS

Potential and/or realized environmental impacts from nuclear materials at the Hanford Site are evaluated using a wide assortment of computer programs. The 25 programs described in this chapter contain mathematical models written in the high-level programming language FORTRAN. Most of these programs operate on one or more medium-size computer systems such as VAX 11/780, UNIVAC 1110 series, CDC 6600-7600 series, or DEC PDP 11, although several of the radiation dosimetry programs have been written for IBM personal computers. Most of the programs are well-documented and include source-code listings and special instructions for computer users. The use of a modular programming format and restricted use of machine-dependent code also appear to be characteristic of most programs. These features allow for easier modification (or upgrading) of the codes and generally increase program transportability.

A summary of the computer programs described in this chapter is provided in Table 5.1. Most of the programs contain mathematical models that fall into one of three generic categories: radiation dose models (12 programs), ground-water transport models (9 programs), or atmospheric dispersion models (1 program).

Radiation dose models are used to calculate dose to selected targets (e.g., organs, individuals, or populations) from all major environmental pathways (i.e., air, soil, water, and food-chain). Calculations may be performed for both acute (one-time) and chronic (single years, human life-times, or thousands of years) exposures. Three types of radiation doses are generally reported:

- <u>one-year dose</u>: the population or individual dose resulting from one year of external plus internal exposure
- <u>committed dose</u>: the population or individual dose resulting from one year of external and internal exposure plus the continued internal dose accumulated from that year's combined inhalation and ingestion exposure

TABLE 5.1. Summary of Computer Programs

Program	Category	Description or Primary Use
ALLDOS	Radiation Dose	Calculates maximum individual and population dose tables for chronic and acute releases
ARRRG	Radiation Dose	Dose from aquatic pathways
BIOPORT/MAXI1	Radiation Dose	Dose from biotic transport processes
CFEST	Ground-water Transport	Coupled fluid, energy, and solute transport in confined aquifers
CHAINT	Ground-water Transport	Radionuclide transport in a fractured porous medium
DACRIN	Radiation Dose	Inhalation dose to individuals from acute or chronic releases
DITTY	Radiation Dose	Collective population dose over a 10,000-year period
FE3DGW	Ground-water Transport	Three-dimensional, finite-element, saturated flow model
FOOD	Radiation Dose	Dose from terrestrial pathways
GENII	Radiation Dose	Second generation of Hanford dosimetry codes
GETOUT	Ground-water Transport	Radionuclide transport through geologic media
ISC	Atmospheric Dispersion	Performs atmospheric dispersion calculations and assesses air quality impacts associated with an industrial source complex
ISOSHLD	Radiation Shielding	Performs gamma ray shielding calculations
KRONIC	Radiation Dose	External individual and population annual dose from chronic releases

TABLE 5.1. Summary of Computer Programs (contd)

MAGNUM-2D	Ground-water Transport	Two-dimensional, coupled heat transfer and ground-water flow in a fractured porous medium
MMT	Ground-water Transport	Radiocontaminant transport in saturated and unsaturated soils
ONSITE/MAXI1	Radiation Dose	Evaluates human intrusion scenarios at low-level radioactive waste sites
ORIGEN2	Radionuclide Inventory	Radionuclide generation and decay code
PABLM	Radiation Dose	Calculates internal radiation doses from external exposure and food pathways
PORFLO	Ground-water Transport	Continuum model for fluid flow, heat transfer, and mass transport in porous media
RADTRAN III	Radiation Dose	Health and economic impacts associated with transportation of radioactive materials
SUBDOSA	Radiation Dose	External doses to individuals from acute releases of radiation
TRANSS	Ground-water Transport	One-dimensional ground-water transport model
UNSAT-H	Ground-water Transport	Unsaturated flow model
VTT	Ground-water Transport	Simulates flow in multilayered aquifer systems

- accumulated dose: the population or individual dose (external plus internal) accumulated over a lifetime (usually 50 or 70 years).

A series of tables have been included in Appendix C that summarize many of the default assumptions used ir the radiation dose models. These tables include assumptions that are generally used to define the agricultural practices and lifestyle characteristics (i.e., dietary and recreational habits) of individuals or populations exposed to radiocontaminants. Metabolic parameters defined for the "Reference Man" (ICRP 1975) are used in all dose models.

A significant upgrade of the radiation dosimetry programs used at Hanford was completed in 1988 as part of the Hanford Environmental Dosimetry Upgrade Project. The new Hanford Environmental Dosimetry System, called Generation II or GENII, provides an integrated package of codes based on existing Hanford models and codes, but includes updated formulations and transfer coefficients. GENII essentially replaces many of the previously used dosimetry programs, including ALLDOS, ARRRG, BIOPORT/MAXI, DACRIN, DITTY, FOOD, ISOSHLD, KRONIC, ONSITE/MAXI, PABLM, AND SUBDOSA. Separate documentation has been provided for these programs in Appendix B.

The ground-water programs described in this chapter actually include a rather wide assortment of hydrologic and hydrogeochemical models. They are used primarily to simulate subsurface flow (saturated and/or unsaturated) and heat and solute transport through geologic media (i.e., soils, fractured rock). Most have been designed to accommodate the unique geologic and climatic features (i.e., flood basalts, arid conditions) that characterize the Hanford Site. They range in sophistication (i.e., size, speed and cost of operation, graphics capabilities, etc.) from relatively simple one-dimensional models, to more complex two- and three-dimensional models.

The Industrial Source Complex (ISC) model is the only atmospheric dispersion model considered in this chapter; however, it should be noted that many of the radiation dose programs also perform atmospheric dispersion calculations.

Listings for each of the programs appearing in this chapter include 1) a general description with a summary of the key features and primary application of each program, 2) a list of important assumptions and/or limitations that apply to each program, 3) special programming considerations, including the software and hardware compatibility of the current version of the program and, if applicable, a list of supplemental documentation, such as user's guides, 4) a current contact with a name and address of an individual (or agency) who can provide updated information on a particular program, and 5) a listing of all relevant source documentation for each program. A current contact may not be listed for programs that are not in current usage or in cases where the principal program author(s) cannot be contacted or is no longer involved with the program. Programs falling into this category have been listed in Appendix A.

In most cases this information has been taken directly from the abstracts, summaries, or introductory sections of the original program documentation. Previous summaries of computer programs (e.g., Strenge, Watson, and Droppo 1976; NRC 1982; EPA 1978) were also used in the preparation of this chapter. Because many programs undergo frequent revision, material documenting their mathematical models and/or computer implementation is often outdated a short time after it is released. Therefore, readers are urged to check with the current contacts if in doubt about the capabilities of a particular program.

Finally, the measurement of uncertainty in the evaluation of model performance deserves special mention. Models use mathematical analogs to describe complex physical and/or chemical processes and, for this reason, often provide a greatly simplified view of the "real world." The ability of a model to provide an accurate simulation of a particular process is dependent on many factors. For instance, errors can result from 1) invalid assumptions concerning key model parameters (i.e., boundary conditions, dispersion characteristics, etc.), 2) the use of inappropriate or overly simplistic analogs, 3) calculational errors in the computer codes, and 4) basic inadequacies in the input data. In some cases program performance may be significantly improved by more rigorous sampling, but additional data collection and/or analysis is often impractical because of time and cost constraints. Serious errors can also arise from model misuse or misinterpretation of program output. Computer programs are designed for specific applications and users must be aware of their limitations. Consultation with the program author(s) or an experienced user should serve to avoid most problems of this nature.

There are several standard procedures for testing the veracity of mathematical models and the computer programs that use them. Model verification involves comparing program output with results generated by hand calculations. Most models are thoroughly verified during the normal course of program development. Program output may also be compared with results from a related, and usually previously verified, model. This is referred to as benchmarking. The most rigorous test of model uncertainty includes some form of field validation. This involves testing model predictions against actual field data or data obtained from laboratory experiments, which simulate conditions similar to those the program was designed to evaluate. Field validation is not an absolute test of model accuracy, however, and great care should be taken in interpreting the results from these kinds of studies. For the most part, validation studies only provide a limited assessment of model performance (i.e., results may only apply to the conditions defined for the test case). Models used to predict long-term trends (e.g., 10,000-year dose) or impacts resulting from postulated accidents, generally cannot be validated. Nevertheless, validation studies provide an additional level of confidence that is highly desirable for engineers, scientists, and management personnel who must make decisions regarding the selection and operation of computer programs used in environmental assessment.

An attempt has been made to acknowledge any verification and/or validation studies that are cited in the original documentation for each of the programs described in this chapter. Regrettably, unpublished work and/or studies appearing in subsequent or supplemental documents may have been overlooked.

5.1 CFEST

The CFEST (Coupled Fluid, Energy, and Solute Transport) program was developed for the U.S. Department of Energy (DOE) as part of the Underground Energy Storage (UES) Program's effort to study the potential use of natural aquifers as hosts for thermal energy storage and retrieval. CFEST provides a multidimensional analysis of coupled fluid, energy, and solute transport and is used to model nonisothermal events in a confined aquifer system.

The program employs a standard Galerkin finite-element methodology and is intended to provide a simulation capability for the evaluation of experimental designs and field data. The program only considers single-phase, Darcian flows but can handle both steady-state and dynamic simulations. Flows are simulated in either a horizontal plane, a vertical plane, or in a fully three-dimensional region within a Cartesian coordinate system. An option also exists for the axisymmetric analysis of a vertical cross section. The program currently employs the bilinear quadrilateral element in all two-dimensional analyses and the trilinear quadrilateral solid in three-dimensional simulations.

CFEST is an extension of the Finite-Element Three-Dimensional Groundwater (FE3DGW, Section 5.2) program. The program is highly interactive and employs a staged execution structure.

Assumptions and/or Limitations

The following assumptions have been incorporated in the CFEST program:

- The flow is transient and laminar (Darcian).
- The permeability and coordinate axes are collinear. The rotation of elements to anisotropy axes is not performed. Finite-element formulations, in general, permit such a rotation. In aquifer problems, horizontal dimensions are far greater than vertical. Therefore, variation between anisotropy axes and the coordinate axes are not significant for regional models. Moreover, field data are also limited by anisotropy properties.
- Fluid density is a function of pressure, temperature, and solute concentration.

- Fluid viscosity is a function of temperature and concentration.
- The injected fluid is miscible with the resident aquifer fluids.
- Aquifer properties (i.e., porosity, permeability, and thickness) vary spatially. The thickness variations are nodal while material properties are element constant.
- Hydrodynamic dispersion is a function of fluid velocity.
- Boundary conditions permit natural water movement in the aquifer; heat losses/gains to adjacent formations; and the location of injection, production, and observation wells anywhere within the system.
- The porous medium and fluid are compressible.
- The fluid and porous media are in thermal equilibrium.
- Rock density and heat capacity remain constant.
- Viscous dissipation is negligible with respect to the energy balance.
- <u>Verification and/or validation studies</u>. CFEST has been the subject of extensive verification efforts (see Chapter 4.0 in Gupta et al. 1982). Solutions have been obtained for a wide range of problems within three broad categories: 1) flow prediction tests (steady and unsteady drawdown in a confined aquifer, unsteady drawdown in a leaky confined aquifer, uniform regional flow with sources and sinks), 2) energy and solute mass transport verifications (Dirichlet upstream boundary condition, mixed upstream boundary condition, approximate analytical solution to an axisymmetric analysis including radially varying velocity), and 3) energy transport including cap and bedrock conduction (Avdonin's radial problem, Avdonin's linear problem, Gringarten-Sauty problem).

<u>Programming Considerations</u>

CFEST is written in FORTRAN and runs on DEC PDP 11/70 computers.

Current Contact

Charles T. Kincaid, K6-77
Battelle, Pacific Northwest Laboratories
Box 999
Richland, WA 99352
509-376-8324

Source

Gupta, S. K., C. T. Kincaid, P. R. Meyer, C. A. Newbill, and C. R. Cole. 1982. A Multi-Dimensional Finite Element Code for the Analysis of Coupled Fluid, Energy and Solute Transport (CFEST). PNL-4260, Pacific Northwest Laboratory, Richland, Washington.

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5.2 FE3DGW

FE3DGW (Finite-Element, Three-Dimensional Ground-Water Flow Model) contains a three-dimensional, finite-element hydrologic model that simulates saturated ground-water flow in a homogeneous or heterogeneous geologic system. The program was developed to anticipate the response of a flow system to natural recharge from rain and various expected and proposed stresses of pumping and/or recharge through wells and streams. FE3DGW defines the ground-water flow field and provides water flow paths and travel times.

FE3DGW can simulate single-layer systems with variable thickness or multilayered systems, where not only thickness can be varied, but the number of layers can be changed to agree with the vertical geologic section. Variable spacing may be used and source or sink terms can be defined at a given point (well), along a given line (rivers, streams, etc.), or for a given region (variable surface infiltration from natural precipitation or irrigation). Pumping stresses in each layer of the subregion can be defined as a function of time.

Assumptions and/or Limitations

The following assumptions have been incorporated in the FE3DGW program (Source: NRC 1982):

- Darcy's law is valid and hydraulic-head gradients are the only significant driving mechanism for fluid flow.
- The porosity and hydraulic conductivity are constant with time.
- Gradients of fluid density, viscosity, and temperature do not affect the velocity distribution.
- The storage term is a function of the compressibility of the fluid and porous medium only.
- The medium is fully saturated.
- Hydraulic conductivity principal axes are aligned parallel to the coordinate axes.

- Verification and/or validation studies. The FE3DGW model has been verified using the radial confined and leaky aquifer solutions documented in Theis (1935) and Hantush (1960), respectively, and the two-dimensional model PATHS (Nelson and Schur 1980). Field applications of FE3DGW include ground-water studies of Long Island, New York (Gupta and Pinder 1978) and Sutter Basin, California (Gupta and Tanji 1976).

Programming Considerations

FE3DGW is written in FORTRAN IV and operates on PDP-11/45 computers. Auxiliary programs are included that plot grid values, contour maps, and three-dimensional charts of both the input data used in the simulation and the resulting output.

Current Contact

Charles R. Cole, K6-77
Battelle, Pacific Northwest Laboratories
Box 999
Richland,WA 99352
509-376-8451

Source

Gupta, S. K., C. R. Cole, and F. W. Bond. 1979. Finite Element Three-Dimensional Ground-Water (FE3DGW) Flow Model Formulation. Program Listings and User's Manual. PNL-2939, Pacific Northwest Laboratory, Richland, Washington.

5.3 GENII

The Hanford Environmental Dose System (Generation II or GENII) includes the second generation of Hanford environmental dosimetry computer codes. This coupled system of computer codes was developed as part of the Hanford Environmental Dosimetry Upgrade Project and incorporates the internal dosimetry models recommended by the International Commission on Radiological Protection (ICRP) (ICRP 1977, 1979) in updated versions of the environmental pathway analysis models used at Hanford.

The GENII system provides a state-of-the-art, technically peer-reviewed, documented set of programs for calculating radiation doses from radionuclides released to the environment. The seven linked computer codes and associated data libraries contained in GENII perform essentially the same calculations as found in previous radiation dosimetry programs. The core system of GENII can calculate annual doses, dose commitments, or accumulated doses from acute or chronic releases of radioactive materials to air or water. These calculations were previously supplied by the computer codes KRONIC (Strenge and Watson 1973), SUBDOSA (Strenge, Watson, and Houston 1975), DACRIN (Houston, Strenge, and Watson 1974; Strenge 1975), ARRRG and FOOD (Napier et al. 1980), and PABLM (Napier, Kennedy, and Soldat 1980). GENII also can calculate annual doses, dose commitments, and accumulated doses from initial contamination of soil or surfaces, thus incorporating capabilities from PABLM and ONSITE/MAXI (Napier et al. 1984; Kennedy et al. 1986; Kennedy et al. 1987). A limited biotic transport capability is included that can simulate the results of BIOPORT/MAXI (McKenzie et al. 1985). GENII contains a modified version of the shielding code ISOSHLD (Engle, Greenborg, and Hendrickson 1966; Simmons et al. 1967) that creates factors relating sources with various geometries to dose rates. An essentially unchanged version of DITTY (Napier, Peloquin, and Strenge 1986) has been added for predicting doses from waste management operations to the public over periods of up to 10,000 years.

The documentation for GENII consists of three volumes. Volume 1 describes the theoretical considerations of the system, including the conceptual diagrams, mathematical representations of the solutions, and descriptions of solution techniques. Volume 2 is a User's Manual providing code structure, user's instructions, required system configurations, and

QA-related topics. Volume 3 is a code Maintenance Manual for the serious user, including code logic diagrams, a global dictionary, worksheets and example hand calculations, and listings of the code and its associated data libraries. A September 1988 release date is anticipated for the completed documentation for GENII.

Assumptions and/or Limitations

The assumptions and/or limitations that apply to the GENII system are nearly identical to those described for the first generation dosimetry codes that have been incorporated in this package. Readers are therefore referred to the detailed descriptions of these codes listed separately in Appendix B.

GENII was developed under a QA plan based on the ANSI standard NQA-1 and has undergone two external peer reviews. All steps of the code development have been thoroughly documented and tested. Worksheets and example hand calculations have been provided in the documentation for GENII.

Programming Considerations

GENII is written in FORTRAN and operates on IBM AT computers (requires a math co-processor) and compatible computers.

Current Contact

Bruce Napier, K3-54
Battelle, Pacific Northwest Laboratories
Box 999
Richland,WA 99352
509-375-3896

Source

Napier, B. A., R. A. Peloquin, D. L. Strenge, and J. V. Ramsdell. 1988. Hanford Environmental Dosimetry Upgrade Project. GENII - The Hanford Environmental Radiation Dosimetry Software System (3 Volumes). Draft, Pacific Northwest Laboratory, Richland, Washington.

5.4 GETOUT

The GETOUT program contains a one-dimensional hydrologic model for predicting radionuclide decay chain transport through geologic media. GETOUT is used to describe the migration of radionuclides from an underground source to a surface body of water.

GETOUT consists of four main FORTRAN programs and associated subprograms. In three of the programs, analytical solutions are computed to describe the migration of single radionuclides and two- and three-member radionuclide chains. In the fourth program, the behavior of more complex chains is modeled by empirical combination of the results from two- and three-member chain calculations. Impulse release and/or band release from the source can be modeled with or without dispersion along the flow path.

Output from the program consists of 1) a time profile of nuclide discharge rates for specified nuclides, and 2) a summary of discharge rate information in a format suitable for use as input to an existing biosphere program (i.e., PABLM/FOOD).

Assumptions and/or Limitations

The following assumptions have been incorporated in the GETOUT program:

- Application is limited to systems that can be represented as a uniform one-dimensional flow path.
- Decay chains of four or more nuclides are approximated using three-member chains.
- Sorption is represented as equilibrium adsorption.
- Elements are assumed to have infinite solubility.
- Steady-state fluid flow is assumed.
- Verification and/or validation studies. GETOUT is widely used in at least three countries and has been subjected to extensive sensitivity analysis. The code has been verified with results from analytic solutions (Burkholder and Rosinger 1980).

Programming Considerations

GETOUT is written in FORTRAN IV and operates on UNIVAC 1100/44 computers. Output from a program such as ORIGEN2 (Section 5.7) is typically used to create the radionuclide inventory file accessed by GETOUT.

Current Contact

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Battelle, Pacific Northwest Laboratories
Box 999
Richland, WA 99352
509-375-2175

Source

DeMier, W. V., M. O. Cloninger, H. C. Burkholder, and P. J. Liddell. 1979. GETOUT-A Computer Program for Predicting Radionuclide Decay Chain Transport through Geologic Media. PNL-2970, Pacific Northwest Laboratory, Richland, Washington.

5.5 ISC

The ISC (Industrial Source Complex) Dispersion Model updates various EPA dispersion algorithms and combines them in a comprehensive program for assessing air quality impacts associated with emissions from an industrial source complex. The ISC model was developed to handle dispersion analysis problems involving complicated source configurations and special atmospheric effects requiring consideration of factors such as fugitive emissions, aerodynamic wake effects, gravitational settling, and dry deposition.

The program consists of two models: the ISC Long-Term (ISCLT) model and the ISC Short-Term (ISCST) model. The ISCST model, an updated version of the EPA Single Source (CRSTER) Model (EPA 1977), uses sequential hourly meteorological data to calculate the average concentration or total dry deposition of emissions for time periods of 1, 2, 3, 4, 6, 8, 12, and 24 hours. Calculation of annual concentration or deposition values is possible if an entire year of sequential hourly meteorological data are available. The ISCLT model is a sector-averaged model that uses statistical wind summaries (tabulation of the joint frequency of occurrence of wind-speed and wind-direction categories, classified according to Pasquill stability categories) to calculate seasonal (quarterly) and/or annual ground-level concentration or deposition values. The ISCLT model extends and combines basic features of the Air Quality Display Model (AQDM) and the Climatological Dispersion Model (CDM). Both the ISCST and ISCLT models can use either a polar- or Cartesian-coordinate receptor grid.

Assumptions and/or Limitations

The following assumptions and/or limitations apply to the ISC program:

- Users are given the option of either entering site- or source-specific data or of using preselected default values for various parameters including wind-profile exponents, vertical potential temperature gradients, plume entrainment coefficients, time-dependent exponential decay of pollutants, stack-tip downwash, building wake effects, plume rise calculated as a function of downwind distance, and dry deposition.

Programming Considerations

The ISC program is written in FORTRAN IV and runs on UNIVAC 1110 computers. However, the programs are designed to operate on most medium-to-large-scale computers with minimal or no modifications. Program modifications required for operation on computers other than UNIVAC 1100 series computers are given in the User's Guide (EPA 1979).

Current Contact

Chief, Environmental Applications Branch
Meteorology and Assessment Division (MD-80)
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

Sources

U.S. Environmental Protection Agency. 1977. User's Manual for Single Source (CRSTER) Model. EPA-450/2-77-013, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

U.S. Environmental Protection Agency. 1979. Industrial Source Complex (ISC) Dispersion Model User's Guide. Vol. I & II. 450/4-79-030 and 450/4-79-031. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

5.6 MMT

MMT (Multicomponent Mass Transfer) was developed to predict the movement of radiocontaminants in the saturated and unsaturated sediments of the Hanford Site. Water movement patterns produced by either an unsaturated or saturated flow model are coupled with dispersion and soil-waste reaction submodels to predict the spatiotemporal distribution and transport of radioactive contaminants.

MMT has undergone several developmental changes and documentation exists for both one- (Washburn et al. 1980) and two-dimensional (Ahlstrom et al. 1977) versions of the program. An analog referred to as the Discrete-Parcel-Random-Walk (DPRW) algorithm is used to simulate mass transport processes in the most recent generation of the program.

MMT is a direct-simulation type of transport analog adapted from an earlier thermal transport model (Eliason and Foote 1972). The advantages of using a direct-simulation model versus the "model-equation" approach include 1) the direct-simulation model is always mass-conservative, 2) there is no cumulative numerical dispersion, 3) the direct-simulation model has greater numerical stability, and 4) it facilitates the handling of multicomponent systems. A principal advantage of MMT over other flow-network codes is its ability to model nuclides that are present as more than one chemical species.

Both graphic and printed output of contaminant release rates are provided by MMT. In addition, output from the one-dimensional version of MMT can be interfaced with programs that calculate dose to humans.

Assumptions and/or Limitations

The documentation for MMT (Ahlstrom et al. 1977) contains a thorough discussion of the critical assumptions and limitations of the various program components. A condensed list of the more important assumptions and/or limitations is provided below.

- When velocity distributions are calculated prior to transport simulation, it is assumed that the advection patterns are not dependent on the chemical composition or temperature of the solution (i.e., momentum, mass, and energy transport processes are decoupled). This assumption is only valid for systems that are nearly isothermal and contain relatively low concentrations of contaminants.

- It is assumed that the relative mass flux can be adequately described by expressions having the form of Fick's First Law.
- MMT uses an engineering-oriented approach to model mass transport that views chemical solutions as systems containing a finite number of discrete particles of matter. Because of computational restrictions, contaminants must be represented by a relatively small number of discrete particles.
- Radionuclide decay chains can only be treated by the one-dimensional version of MMT.
- Verification and/or validation studies. MMT has been compared with analytic results obtained from GETOUT (Section 5.4). The two-dimensional version of MMT has been used to model the migration of tritium at the Hanford Site. An error and sensitivity analysis for MMT is documented in Ahlstrom et al. (1977).

Programming Considerations

MMT is written in FLECS, a high-order language which compiles into FORTRAN IV, and operates on DEC PDP 11/70 and 11/45 computers.

Current Contact

C. S. Simmons, K6-77 (one-dimensional version)
Pacific Northwest Laboratory
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Richland, WA 99352
509-376-8317

Sources

Ahlstrom, S. W., H. P. Foote, R. C. Arnett, C. R. Cole, and R. J. Serne. 1977. Multicomponent Mass Transport Model: Theory and Numerical Implementation (Discrete-Parcel-Random-Walk Version). BNWL-2127, Pacific Northwest Laboratory, Richland, Washington.

Eliason, J. R. and H. P. Foote. 1972. Long Beach Generating Station Thermal Transport Modeling Study. Prepared for the Southern California Edison Company by Battelle, Pacific Northwest Laboratories, Richland, Washington.

Washburn, J. F., F. E. Kaszeta, C. S. Simmons, and C. R. Cole. 1980. Multicomponent Mass Transport Model: A Model for Simulating Migration of Radionuclides in Groundwater. PNL-3179, Pacific Northwest Laboratory, Richland, Washington.

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5.7 ORIGEN2

ORIGEN2 is a versatile point depletion and decay program for use in simulating nuclear fuel cycles and calculating the nuclide compositions of various nuclear materials. The original ORIGEN program (Bell 1973) was designed for use in generating spent-fuel and waste characteristics (composition, thermal power, etc.) that would form the basis for the study and design of fuel reprocessing plants, spent fuel shipping casks, waste treatment and disposal facilities, and waste shipping casks. Enhancements appearing in ORIGEN2 include 1) substantial changes to the input/output and control features of the computer program, 2) the inclusion of relatively sophisticated reactor physics calculations for different reactor/fuel combinations, and 3) calculation of spectrum-weighted cross sections and fission product yields for approximately 230 nuclides.

ORIGEN2 uses the matrix exponential method to solve a large system of coupled, linear, first-order ordinary differential equations with constant coefficients. The matrix exponential technique was developed to solve a nonhomogeneous system of equations, which makes it possible for ORIGEN2 to be used in calculating the accumulation of radioactivity in processing plants, waste disposal operations, and in the environment.

Assumptions and/or Limitations

The following assumptions and/or limitations apply to the ORIGEN2 program:

- Nuclear transmutation and decay are represented as a simultaneous system of linear, homogeneous, first-order ordinary differential equations with constant coefficients.
- The build-up and depletion of nuclides during irradiation is calculated using zero-dimensional (i.e., point) geometry and quasi-one-group neutron cross sections. This means that ORIGEN2 cannot account for spatial or resonance self-shielding effects or changes in the neutron spectrum other than those initially encoded.
- Elemental chemical toxicity used in ORIGEN2 are from Dawson (1974).

Programming Considerations

ORIGEN2 is written in FORTRAN and versions are available that run on IBM and CDC-compatible computers. A separate user's manual for ORIGEN2 is documented in Croff (1980). An extensive library of nuclear data (half-lives and decay schemes, neutron absorption cross sections, fission yields, disintegration energies, and multigroup photon release data) is included with the program.

Current Contact

Codes Coordinator
Radiation Shielding Information Center
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Oak Ridge, TN 37330

Sources

Bell, M. J. 1973. ORIGEN-The ORNL Isotope Generation and Depletion Code. ORNL-4628, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Croff, A. G. 1980. ORIGEN2: A Revised and Updated Version of the ORNL Isotope Generation and Depletion Code. ORNL-5621, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Croff, A. G. 1980. A User's Manual for the ORIGEN2 Computer Code. ORNL/TM-7175, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Dawson, G. W. 1974. The Chemical Toxicity of Elements. BNWL-1815, Pacific Northwest Laboratory, Richland, Washington.

5.8 PORFLO

PORFLO contains a continuum model for fluid flow, heat transfer, and mass transport and was written for assessing the post-closure performance of a proposed high-level nuclear waste repository at the Hanford Site. The program is specifically designed to accommodate the layered nature of the flood basalts found at this site.

PORFLO uses a series of parabolic differential equations, coupled through time-varying parameters, to provide numerical solutions to fluid flow, heat transfer, and mass-transport problems. The governing equations are derived from the principles of conservation of mass, momentum, and energy in a stationary control volume that is assumed to contain a heterogeneous, anisotropic porous medium.

The numerical method of nodal-point integration is used to discretize the governing equations over a nonuniform net of rectangular elements. Various techniques such as the alternating direction implicit method and Choleski decomposition are used to solve the set of algebraic equations. PORFLO uses either a two-dimensional Cartesian coordinate system or a three-dimensional axisymmetric cylindrical coordinate system. In the coupled mode, the governing equations are solved sequentially starting with the fluid flow equation, followed by the heat transfer equation, and ending with the mass-transport equation. An option in the program allows the user to solve the equations either individually or in sets of two.

Assumptions and/or Limitations

The following assumptions have been incorporated in the PORFLO program:

- The porous media and the fluid are continua that are at least piecewise continuous.
- The porous media and the fluid are only slightly compressible so that equations can be derived in a fixed (rather than deforming) coordinate system.
- The fluid velocity is small so that inertia terms are negligible and Darcy's law is applicable.

- Variation of fluid density and viscosity with fluid pressure is negligibly small.
- Variations in the porosity of the porous medium as a result of stress changes have been ignored.
- Heat and mass transport caused by Dufour and Sorret effects, respectively, are negligible.
- Dispersive heat and mass transport can be described by a linear gradient law.
- The porous medium and the fluid are in thermal equilibrium at all times.
- Adsorption and desorption are the only chemical processes considered. It is assumed that they occur at high speed and that equilibrium is attained instantaneously.
- A linear isotherm is assumed to describe the adsorption/desorption process.
- Verification and/or validation studies. PORFLO has been tested by comparing simulation results with 1) analytic solutions, 2) results from independently developed numerical models, such as MAGNUM-2D, and 3) laboratory and field data. A separate verification and benchmarking report for PORFLO is documented in Eyler and Budden (1984).

Programming Considerations

PORFLO Version 5.6 is written in FORTRAN IV and operates on PRIME 240 and 750 computers. A separate User's Guide for PORFLO is documented in Kline, Runchal, and Baca (1983). Both three-dimensional (PORFLO3) and Monte Carlo (PORMC-SF) versions of PORFLO have been developed, but documentation for these programs is unavailable at this time. A partially saturated version of PORFLO3 is currently under development.

Current Contact

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Sources

Eyler, L. L., and M. J. Budden. 1984. Verification and Benchmarking of PORFLO: An Equivalent Porous Continuum Code for Repository Scale Analysis. PNL-5044, Pacific Northwest Laboratory, Richland, Washington.

Kline, N. W., A. K. Runchal, and R. G. Baca. 1983. PORFLO Computer Code: User's Guide. RHO-BW-CR-138 P, Rockwell Hanford Operations, Richland, Washington.

Runchal, A. K., B. Sagar, R. G. Baca, and N. W. Kline. 1985. PORFLO-A Continuum Model for Fluid Flow, Heat Transfer, and Mass Transport in Porous Media: Model Theory, Numerical Methods, and Computational Tests. RHO-BW-CR-150 P, Rockwell Hanford Operations, Richland, Washington.

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5.9 RADTRAN III

RADTRAN III is used to evaluate possible health and economic impacts associated with the transportation of radioactive materials. The program uses a combination of meteorological, demographic, health physics, transportation, packaging, and material factors to analyze risks associated with both normal transport (incident free) and various user-selected accident scenarios.

The RADTRAN III program consists of seven submodels: 1) a material model that allows users to select basic material parameters including number of curies per package, average total photon energy per disintegration, the rate at which released material is deposited on the ground, cloudshine dose factors, the physical character of the waste, half-life, and measures of the radiotoxicity of the dispersed material; 2) a transportation model that considers accident rates for each transportation mode (truck, van, rail, cargo and passenger air, barge, and ship), traffic patterns (fraction of travel occurring on various road types, through different population zones, and under both rush-hour and normal traffic conditions), and basic shipment information (number of crew per vehicle, handling and storage times, duration and number of stops); 3) an accident severity and package release model that classifies accidents according to severity (i.e., fire; crush, impact, and puncture forces) and defines the respirable fraction (particles <10 μm) of airborne material released from packages; 4) a meteorological dispersion model that describes the diffusion of a cloud of aerosolized debris released during an accident; 5) a population distribution model that describes the distribution and relative densities of people in three population zones (rural, suburban, and urban), and in certain specific areas, such as pedestrian walkways, warehouses, and air terminals; 6) a health effects model that evaluates the radiotoxicity of materials in terms of potential for producing acute fatalities, early morbidities, genetic effects, and latent cancer fatalities; and 7) an economic model that evaluates the economic impacts connected with surveillance, cleanup, evacuation, and long-term land-use denial activities.

The radiological impacts from transportation accidents are expressed according to the level of consequence, probability of occurrence, and level of risk. A risk figure-of-merit is calculated by summing the products of the probability of each specific accident and its associated level of consequence.

Assumptions and/or Limitations

The following assumptions have been incorporated in the RADTRAN III program:

- Dose calculations in the population exposure model assume that the package or shipping cask is a point source of radiation.
- Radioactive materials released from a package during an accident are assumed to be dispersed according to standard Gaussian diffusion models.
- External radiation exposures from ground contamination are calculated using an infinite plane source model (Taylor and Daniel 1982).
- Verification and/or validation studies. Sensitivity analyses have been performed for several applications (i.e., incident-free transportation, vehicular accidents) of the RADTRAN III program and are documented in Madsen et al. (1986).

Programming Considerations

RADTRAN III is written in FORTRAN V and runs on CDC 6600-7600 series and CRAY computers. A separate user's manual (Madsen, Wilmot, and Taylor 1983) documents the various options for generating accident scenarios and provides additional instructions for computer operators.

Current Contact

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Sources

Madsen, M. M., E. L. Wilmot, and J. M. Taylor. 1983. RADTRAN II User's Guide. SAND82-2681, Sandia National Laboratories, Albuquerque, New Mexico.

Madsen, M. M., J. M. Taylor, R. M. Ostmeyer, and P. C. Reardon. 1986. RADTRAN III. SAND84-0036, Sandia National Laboratories, Albuquerque, New Mexico.

Taylor, J. M., and S. L. Daniel. 1982. RADTRAN II: A Revised Computer Code to Analyze Transportation of Radioactive Material. SAND80-1943, Sandia National Laboratories, Albuquerque, New Mexico.

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5.10 TRANSS

TRANSS contains a simplified ground-water transport model and can be used to estimate the rate of migration of a decaying radionuclide that is subject to sorption governed by a linear isotherm. TRANSS employs simple analytical solutions of the advection-dispersion equation to describe solute movement along a collection of hydrologic streamlines composing a hypothetical streamtube. Local dispersion along a streamtube is treated as a combination of advection and Fickian diffusion, based on an effective dispersion coefficient.

Contaminant release from a source is described in terms of a fraction-remaining curve provided as input information. An option in the program allows for the calculation of a fraction-remaining curve based on four specialized release models: 1) constant release rate, 2) solubility-controlled release, 3) adsorption-controlled release, and 4) diffusion-controlled release from beneath an infiltration barrier.

Assumptions and/or Limitations

The following assumptions have been incorporated in the TRANSS program:

- It is assumed that contaminant transport can be represented by a collection of one-dimensional problems defined by the streamlines of a flow field under steady-state conditions.
- Transverse dispersion within a streamtube is assumed to be negligible.
- Travel times along streamlines must be obtained from a prior ground-water flow simulation.
- TRANSS is not a predictive program. The program is intended to be used as a scoping tool for estimating the relative influence of transport controlling parameters. Moreover, output estimates depend conditionally on the specific ground-water flow field used as input.
- Verification and/or validation studies. TRANSS has been verified for a number of sample problems, including well-documented test cases involving the transport of single radionuclides (Simmons and Cole 1985).

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Sources

Simmons, C. S., and C. R. Cole. 1985. Guidelines for Selecting Codes for Ground-Water Transport Modeling of Low Level Waste-Burial Sites. PNL-4980, Vol. 2, Pacific Northwest Laboratory, Richland, Washington.

Simmons, C. S., C. T. Kincaid, and A. E. Reisenauer. 1986. A Simplified Model for Radionuclide Contaminant Transport: The TRANSS Code. PNL-6029, Pacific Northwest Laboratory, Richland, Washington.

5.11 UNSAT-H

UNSAT-H contains a hydrologic model for simulating water flow in unsaturated soils and is used primarily for assessing the water dynamics of arid sites under consideration for near-surface waste disposal. The program can be used to predict deep drainage (i.e., recharge) as a function of environmental conditions such as climate, soil type, and vegetation. An additional application includes the simulation of various waste-management practices, such as placing surface barriers over waste sites.

UNSAT-H employs a one-dimensional, mechanistic model that simulates the dynamic processes of infiltration, drainage, redistribution, surface evaporation, and uptake of water from soil by plants. The mathematical basis of the model is Darcy's Law of water flow as extended to unsaturated systems by Richards (1931). The basic numerical implementation is patterned after the UNSAT model of Gupta et al. (1978).

UNSAT-H uses a fully implicit, finite-difference method for solving the water transport equation. Plant water uptake is introduced as a sink term at each node and is calculated as a function of root density, moisture content, and potential evapotranspiration. The simulated soil profile can be homogeneous or layered. The boundary conditions can be controlled as either constant head or flux conditions depending on the specific conditions at a given site.

Features of UNSAT-H that are improvements over earlier programs, such as UNSAT, include a cheatgrass transpiration function, additional options for describing soil hydraulic properties, consideration of isothermal vapor flow, and reduction of mass-balance error.

Output from UNSAT-H consists of the following: 1) hourly or daily summaries of water content, water potential, flux, and plant water use as a function of depth, and 2) cumulative totals of the water balance components (storage, precipitation, evaporation, transpiration, and drainage).

Assumptions and/or Limitations

In evaluating the limitations of UNSAT-H, Fayer et al. (1986) have listed four modifications or enhancements that are being considered for inclusion in future upgrades of the program:

- Design of a mechanistic transpiration algorithm that includes plant growth and development.
- Development of a diffusion-based evaporation algorithm.
- Inclusion of soil temperature predictions to account for nonisothermal effects during evaporation or freezing of soils.
- Changes to precipitation and evaporation algorithms to account for extended snow cover and snowmelt.
- Verification and/or validation studies. Extensive verification tests have been performed using UNSAT1D (see Simmons and Cole 1985), a program related to UNSAT-H. These tests evaluated the ability of UNSAT1D to model infiltration, redistribution, and drainage processes. The UNSAT-H program has been tested using measured field data from the 200-Area closed-bottom lysimeter (Fayer, Gee, and Jones 1986, Appendix B). Fayer, Gee, and Jones (1986) also contains a verification test for infiltration and redistribution processes.

Programming Considerations

UNSAT-H Version 1.1 is written in VAX FORTRAN Version 4.0 and runs under the VAX/VMS Version 4.0 Operating System.

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Sources

Fayer, M. J., G. W. Gee, and T. L. Jones. 1986. UNSAT-H Version 1.0: Unsaturated Flow Code Documentation and Applications for the Hanford Site. PNL-5899, Pacific Northwest Laboratory, Richland, Washington.

Gupta, S. K., K. K. Tanji, D. R. Nielson, J. W. Briggar, C. S. Simmons, and J. L. MacIntyre. 1978. Field Simulation of Soil-Water Movement with Crop Water Extraction. Water Science and Engineering Paper No. 4013, Department of Land, Air, and Water Resources, University of California, Davis, California.

Richards, L. A. 1931. "Capillary Conduction of Liquids in Porous Mediums." Physics 1:318-333.

Simmons, C. S. and C. R. Cole. 1985. Guidelines for Selecting Codes for Ground-Water Transport Modeling of Low Level Waste-Burial Sites. PNL-4980, Vol. 2, Pacific Northwest Laboratory, Richland, Washington.

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5.12 VTT

The VTT (Variable Thickness Transient) ground-water modeling system is a collection of programs used for assessing the far-field, long-term, post-closure safety of deep geologic nuclear waste repositories. VTT defines the ground-water flow field and provides water flow paths and travel times for multilayer aquifer systems. A Boussinesq approximation method is used to provide a simplified, two-dimensional view of confined, unconfined or semiconfined ground-water systems.

Three separate versions of the program, each utilizing different solution techniques to solve the same set of equations, have been created to handle specific problems. The VTT version solves the transient form of the system of finite-difference equations using the successive line over-relaxation technique. For transient problems the solution is stable and convergent with sufficient speed to make solution of large matrices practical. The VTTSS3 version utilizes a Newton iteration technique and is primarily used for a system of aquifers in which one is confined and, therefore, the equations are non linear. Convergence of this method is quadratic in nature and for most ground-water problems the solution is reached in four to five iterations. The VTTSSZ version uses a Colesky decomposition method and is used when all of the aquifers being simulated are confined.

Assumptions and/or Limitations

VTT is a quasi-three-dimensional code in that it simplifies the solution of three-dimensional flow equations by transforming them into a series of coupled two-dimensional problems. This assumption would not be valid for aquifers with three-dimensional flow-fields. Specific assumptions of the Boussinesq flow model used for describing saturated unconfined flow include the following:

- Flow is by an incompressible fluid that saturates a rigid, porous soil matrix.

- Compressibility effects of the fluid and soil matrix can be neglected under conditions of unconfined or free-surface flow; however, they are incorporated into the storage term for confined flow.

- Hydraulic conductivity and effective porosity can be represented by the vertical average values and are isotropic but non-homogeneous throughout the region.

- The free-surface slope and the aquifer bottom slope are both assumed to be slight (<5°).

- Vertical velocities are assumed to be small and therefore can be neglected.

- Coefficient distributions are dependent variables and are assumed continuous over the simulation region.

- Flow in the capillary fringe is neglected.

- Seepage surfaces cannot be handled and are therefore neglected.

- Verification and/or validation studies. Output from VTT has been compared with solutions obtained from both two-(PATHS, Nelson and Schur 1980) and three-dimensional (FE3DGW, Section 5.2) models.

Programming Considerations

VTT is written in FORTRAN IV-PLUS and runs on PDP 11/45 computers.

Current Contact

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Source

Reisenauer, A. E. 1979. Assessment of Effectiveness of Geologic Isolation Systems. Variable Thickness Transient Ground-Water Flow Model. Vol. 1 Formulation, PNL 3160-1; Vol. 2 User's Manual, PNL 3160-2; Vol. 3 Program Listings, PNL 3160-3, Pacific Northwest Laboratory, Richland, Washington.

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APPENDIX A

MODELS WITH NO CURRENT CONTACT

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CHAINT

CHAINT contains a two-dimensional hydrologic model that can be used to analyze radionuclide transport in a fractured porous medium. CHAINT is a deterministic, waste package-scale (very near-field) code that accounts for the physical processes of advection, dispersion, diffusion, retardation, radionuclide chain decay coupling, and mass injection.

CHAINT employs a computational scheme based on a Galerkin finite-element method and block-diagonal frontal solution technique. The program is applicable to problems that can be formulated in two dimensions using rectangular coordinates or axisymmetric radial coordinates. Continuum portions of the medium are modeled with two-dimensional isoparametric elements, and discrete features are modeled with one-dimensional elements that are embedded along the sides of the continuum elements.

Principal input to the program consists of files from a previous MAGNUM-2D (Appendix A) simulation of buoyancy driven fluid flow. Output from CHAINT includes a printed report of contaminant concentrations along with postprocessor graphics files.

Assumptions and/or Limitations

The following assumptions have been incorporated in the CHAINT program:

- The diffusive flux is assumed to be Fickian.
- Radionuclide transport occurs only in fractures.
- Sorption may be represented by equilibrium adsorption.
- The assumptions incorporated in MAGNUM-2D also apply to CHAINT (refer to Appendix A).

Programming Considerations

CHAINT Version 2.1 is written in FORTRAN 77 and operates on PRIME 750 minicomputer networks. Earlier versions were written to run on UNIVAC 1100/44, CRAY 1, and PRIME minicomputers. Transportability of the program has been given a high priority, and most features of the current version are machine independent. A set of support codes and graphics software has been developed and interfaced with the CHAINT code to 1) generate, manipulate, and display the finite-element grid, 2) compute and plot the mass flux across selected boundaries, and 3) plot contours, spatial cross sections, and time histories of concentrations.

Sources

King, I. P., D. B. McLaughlin, W. R. Norton, R. G. Baca, and R. C. Arnett. 1981. Parametric and Sensitivity Analysis of Waste Isolation in a Basalt Medium. RHO-BWI-C-94, Rockwell Hanford Operations, Richland, Washington.

Kline, N. W., R. L. England, and R. G. Baca. 1986. CHAINT Computer Code: User's Guide, RHO-BW-CR-144 P, Rockwell Hanford Operations, Richland, Washington.

MAGNUM-2D

MAGNUM-2D contains a two-dimensional hydrologic model for transient or steady-state analysis of coupled heat transfer and ground-water flow in a fractured porous medium. The program was developed for simulating the thermal and hydraulic conditions in the vicinity of a waste package emplaced in a deep geologic repository. MAGNUM-2D is used to calculate 1) the temperature field surrounding the waste package as a function of the heat generation rate of the nuclear waste and thermal properties of the basalt, and 2) the hydraulic head distribution and associated ground-water flow fields as a function of the temperature gradients and hydraulic properties of the basalt.

The governing equations in MAGNUM-2D consist of a set of coupled, quasi-linear partial differential equations that are solved using a Galerkin finite-element technique. A Newton-Raphson algorithm is embedded in the Galerkin function to formulate the problem in terms of the incremental changes in the dependent variables. Both triangular and quadrilateral finite elements are used to represent the continuum portions of the spatial domain. Line elements may be used to represent flow in discrete conduits or fractures (macroscale discontinuities).

Assumptions and/or Limitations

The following assumptions have been incorporated in the MAGNUM-2D program (Source: U.S. NRC 1982):

- The fractured-porous medium is nondeformable.
- The fluid is slightly compressible.
- Flow is laminar (Darcian).
- Macroscale hydraulic gradients are independent of fracture orientation or geometry.
- The fluid system is single-phase.
- The medium is fully saturated.
- Moisture is stored in both primary and secondary pores.

- Flow in fractures is governed by a nonisothermal version of Darcy's law.
- Flow between primary and secondary pores depends on the difference between primary and secondary heads.
- Heat flux is governed by the convection-diffusion equation.
- Conservation of mass applies separately in the primary and secondary storage systems, but conservation of energy applies in the system as a whole.
- Verification and/or validation studies. The ground-water flow and energy transport components of MAGNUM-2D have been verified against analytic solutions obtained from the SEMTRA program (a forerunner of MAGNUM-2D) for three classes of problems: 1) a simplified flow problem, 2) a thermal dispersion problem, and 3) a coupled heat and fluid flow (non-isothermal) problem.

Programming Considerations

MAGNUM-2D Version 3.1 is written in FORTRAN 77 and operates on PRIME 750 minicomputer networks. Earlier versions of the program were designed to run on UNIVAC 1100/44, CRAY 1, and PRIME computers. Transportability of the program has been given a high priority and most features of the code are machine independent. A set of support codes and graphics software has been developed and interfaced with the MAGNUM-2D program to 1) generate, manipulate, and display the finite element grid, 2) compute and plot pathlines/streamlines and travel times, and 3) plot contours, spatial cross sections, and time histories for temperature and hydraulic head.

Sources

Baca, R. G., R. C. Arnett, and I. P. King. 1981. Numerical Modeling of Flow and Transport in a Fractured-Porous Rock System. RHO-BWI-SA-113, Rockwell Hanford Operations, Richland, Washington.

England, R. L., N. W. Kline, K. J. Ekblaw, and R. G. Baca. 1985. MAGNUM-2D Computer Code: User's Guide. RHO-BW-CR-143 P, Rockwell Hanford Operations, Richland, Washington.

King, I. P., D. B. McLaughlin, W. R. Norton, R. G. Baca, and R. C. Arnett. 1981. Parametric and Sensitivity Analysis of Waste Isolation in a Basalt Medium. RHO-BWI-C-94, Rockwell Hanford Operations, Richland, Washington.

APPENDIX B

FIRST GENERATION OF HANFORD DOSIMETRY CODES

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ALLDOS

ALLDOS was developed to calculate radiation doses from postulated releases of aged radioactive wastes. The program is used primarily as a "report generator" to calculate maximum individual and population dose tables from release inventories and dose conversion factors. ALLDOS considers both chronic and acute releases of radiation.

ALLDOS uses three release terms in describing exposure scenarios: 1) airborne release for external and inhalation exposure, 2) airborne release for terrestrial pathways (ingestion/external), and 3) waterborne releases for terrestrial and aquatic pathways (ingestion/external). Separate release terms are defined for each release pathway and an optional procedure is provided to generate release terms from a basic radionuclide inventory. ALLDOS relies heavily on the use of precalculated dose conversion factors to describe terrestrial pathways and radiation dosimetry. Dose conversion factors defined for each release pathway are used to generate dose commitments to a maximum individual and the population in the region of the release site.

Output from ALLDOS consists of the dose contribution from each release pathway plus the total dose to selected organs. The dose contribution fraction by radionuclide for each organ is also reported as an option.

Assumptions and/or Limitations

The following assumptions have been incorporated in the ALLDOS program:

- Inhalation dose conversion factors are obtained from the program DACRIN (Appendix B). Calculations in DACRIN are based on the respiratory tract model adopted by the International Commission on Radiological Protection (ICRP) Task Group on Lung Dynamics (ICRP 1966; ICRP 1972).
- ALLDOS uses the gastrointestinal tract and organ retention models documented in ICRP Publication 2 (ICRP 1959).
- Dose conversion factors for terrestrial and aquatic pathways are obtained from the program PABLM (Appendix B). Dose conversion factors are based on site-specific assumptions concerning various

demographic and lifestyle (i.e., dietary and recreational habits) features of the exposed population.

- A tissue depth of 5 cm is assumed in calculating external doses to blood-forming organs, and this approximation is used to determire the dose contributions to all organs.
- Radioactive decay in transit from the release point to the location of exposure is ignored because ALLDOS calculates doses for aged radioactive wastes containing nuclides with relatively long half-lives.

Programming Considerations

ALLDOS is written in ASCII FORTRAN and versions are available that operate on IBM PC and VAX 11/780 computers.

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Source

Strenge, D. L., B. A. Napier, R. A. Peloquin, and M. G. Zimmerman. 1980. ALLDOS-A Computer Program for Calculation of Radiation Doses from Airborne and Waterborne Releases. PNL-3524, Pacific Northwest Laboratory, Richland, Washington.

ARRRG

ARRRG (Aqueous Reactor Release Result Generator) and its companion program FOOD (Appendix B) provide rapid estimates of the radiation dose and dose commitment to man resulting from radioactive materials released to the environment. ARRRG was written to address aquatic exposure routes, and can calculate doses for five ingestion pathways (fish, mollusks, crustaceans, plants, and drinking water) and three external pathways (swimming, boating, and shoreline exposure).

The fundamental equations used in the ARRRG program are documented in Soldat et al. (1974). The program calculates dose for either a maximally exposed individual or for a population. ARRRG calculates 1-year doses and dose commitments for any one or a combination of radionuclides for which sufficient biological data are available. As many as five of 23 possible organs and tissues, and mixtures of up to 100 radionuclides, may be selected for any one exposure scenario. Calculations are based on chronic exposures, although equations are included that can treat acute (one-time) exposures.

The output from ARRRG consists of 1) radiation dose and dose commitment summaries for all chosen organs listed by exposure pathway and by radionuclide, 2) complete listing of dose contributions by radionuclide for each pathway (optional), and 3) radionuclide concentrations in all ingested plant and animal material.

Assumptions and/or Limitations

The following assumptions have been incorporated in the ARRRG program:

- The equations for calculating internal dose and dose commitment are derived from those given by the ICRP for body burdens and Maximum Permissible Concentration (MPC) of each nuclide (ICRP 1959). Metabolic parameters for the Reference Man (ICRP 1975) are used.
- Usage parameters (i.e., duration of exposure to external sources of radiation and intake rates of ingested food and water) for the average adult are assumed in population dose calculations.

- Radionuclide concentrations in the sediments of a river or lake downstream from a discharge point are calculated by assuming that 1) there is a constant water concentration for each year of the release, 2) the deposition rate to the sediment is dependent only on water concentration and, 3) removal from the sediments is only by radioactive decay.
- The radiation dose to individuals swimming in contaminated water is calculated by assuming that the body of contaminated water is large enough to be considered an "infinite medium" relative to the range of emitted radiations.
- An "infinite" flat-plane source model is used to calculate radiation doses from contaminated shorelines. A factor of two is included to account for surface roughness. Shoreline calculations include a modifying factor to compensate for finite extent.
- Persons boating on contaminated water are assumed to be exposed to a dose rate half that of swimmers.

Programming Considerations

ARRRG is written in ASCII FORTRAN and runs on UNIVAC 1100/44 computers. Older versions of the program written in Basic are no longer maintained at PNL.

Current Contact

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Sources

Napier, B. A., R. L. Roswell, W. E. Kennedy, Jr., and D. L. Strenge. 1980. ARRRG and FOOD-Computer Programs for Calculating Radiation Dose to Man from Radionuclides in the Environment. PNL-3180, Pacific Northwest Laboratory, Richland, Washington.

Soldat, J. K., N. M. Robinson, and D. A. Baker. 1974. Models and Computer Codes for Evaluating Environmental Radiation Doses. BNWL-1754, Pacific Northwest Laboratory, Richland, Washington.

BIOPORT/MAXI1

BIOPORT/MAXI1 is a collection of computer programs designed to estimate the potential radiation dose to man resulting from biotic transport processes at low-level nuclear waste disposal sites. Dose to man is calculated for ingestion of agricultural crops grown in contaminated soil, inhalation of resuspended radionuclides, and direct exposure to penetrating radiation from soil. In addition to biotic transport, models are included for erosion of soil from the burial site cover and waste package decomposition.

Five programs are contained within the BIOPORT/MAXI1 package: CREATE, an interactive program that allows an end-user to create and evaluate biotic transport scenarios; BIOPORT, which simulates the redistribution of radionuclides by plant and animal processes following intrusion into buried waste and, at specified years during the simulation, calculates soil concentrations of radionuclides; MAXI1, which uses these nuclide concentrations and a standard maximally exposed individual scenario to calculate the maximum annual dose to the exposed individual from the various pathways; and MAXI2 and MAXI3, which generate intermediate dose conversion factors for food and aquatic pathways, and allow experienced users complete access to MAXI1 capabilities.

Assumptions and/or Limitations

The exposure scenarios used in BIOPORT/MAXI1 are based on user-created "reference environments" that define the agricultural and water-usage practices for a particular geographic area and the general lifestyle (i.e., dietary and recreational habits) characteristics of a hypothetical intruder/resident. Users are given the option of either running the default scenarios contained within the program or entering their own baseline data to generate unique scenarios for specific applications. The following assumptions have been incorporated in the BIOPORT/MAXI1 program:

- A maximally exposed individual scenario is assumed throughout the program. The largest of the annual organ doses calculated to occur during a 50-year period of continuing exposure is used in determining the maximum annual radiation dose.

- Intrusion and active physical transport are assumed to be the dominant biotic transport mechanisms; transport enhancement and secondary transport are not considered.

Programming Considerations

BIOPORT/MAXI1 is written in ANSI FORTRAN-77 and was developed initially to run on VAX 11/780 computers. McKenzie et al. (1985) describes changes to the program that are required for operation on CDC 6600-7600 series computers. A database of dose conversion factors (external, soil and leaf mechanism, and inhalation dose conversion factors) and radiological decay information is included with the computer software. Inhalation dose conversion factors are calculated using DACRIN (Appendix B). External dose conversion factors for various waste disposal geometries are calculated using the ISOSHLD (Appendix B) shielding program.

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Sources

McKenzie, D. H., L. L. Cadwell, L. E. Eberhardt, W. E. Kennedy, Jr., R. A. Peloquin, and M. A. Simmons. 1982. Relevance of Biotic Pathways to the Long-Term Regulation of Nuclear Waste Disposal, Topical Report on Reference Western Arid Low-Level Sites. NUREG/CR-2675, Vol. 2, U.S. Nuclear Regulatory Commission, Washington, D.C.

McKenzie, D. H., L. L. Cadwell, K. A. Gano, W. E. Kennedy, Jr., B. A. Napier, R. A. Peloquin, L. A. Prohammer, and M. A. Simmons. 1985. Relevance of Biotic Pathways to the Long-Term Regulation of Nuclear Waste Disposal. Estimation of Radiation Dose to Man Resulting from Biotic Transport: The BIOPORT/MAXI1 Software Package. NUREG/CR-2675, Vol. 5, (PNL-4241), U.S. Nuclear Regulatory Commission, Washington, D.C.

DACRIN

DACRIN is used to generate rapid estimates of the radiation dose to the human respiratory tract and other organs from the inhalation of radioactive aerosols. The program performs dose calculations for up to 22 organs and tissues (maximum of 10 organs/tissues per run). Organ doses are calculated based on the quantity of radionuclide inhaled or, if air dispersion and other supplemental data are provided, for the quantity released to the atmosphere.

DACRIN is based on the respiratory tract model adopted by the ICRP Task Group on Lung Dynamics (ICRP 1966, 1972) and a simple exponential model that calculates radionuclide retention for selected organs and tissues. Mathematical models describing atmospheric dispersion have been included for evaluating doses resulting from either accidental or chronic atmospheric releases of radionuclides.

Output from DACRIN consists of the effective radiation dose to all organs or tissues of interest at selected time intervals for each radionuclide inhaled.

Assumptions and/or Limitations

The following assumptions have been incorporated in the DACRIN program:

- The lung model simplifies calculations of radionuclide deposition and clearance by dividing the respiratory tract into three regions: the nasopharyngeal, tracheobronchial, and pulmonary. Each region is further subdivided into two or more subcompartments, each representing the fraction of material (f_k) initially in a compartment that is subject to a particular clearance process. Clearance half-times and values of f_k for each clearance process and for the three solubility classes of aerosols used in the code are taken from ICRP (1972).
- A constant fraction of the material clearing from the respiratory tract through the GI tract is assumed to be taken up by the blood. A constant fraction of material from the blood is assumed to enter each organ or tissue, and subsequent clearance from the organ or tissue is assumed to occur at a constant rate.

- The bivariate-normal distribution model is used in calculating radionuclide concentrations in air at specified distances from the source.
- The organ dose from daughter nuclides is computed indirectly by utilizing weighted values of the effective energy emitted by the daughter nuclides in the chain.

Programming Considerations

DACRIN is written in FORTRAN-77 and runs on VAX 11/780 computers.

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Sources

Houston, J. R., D. L. Strenge, and E. C. Watson. 1974. DACRIN-A Computer Program for Calculating Organ Dose from Acute or Chronic Radionuclide Inhalation. BNWL-B-389, Pacific Northwest Laboratory, Richland, Washington.

Strenge, D. L. 1975. DACRIN-Modification for Gastrointestinal Tract Dose. BNWL-B-399, Supplement 1. Pacific Northwest Laboratory, Richland, Washington.

DITTY

DITTY (Dose Integrated over Ten Thousand Years) is used to calculate the collective radiation dose to man from long-term nuclear releases to the environment from any source. DITTY estimates the time integral of collective dose over a 10,000-year period for time-variant radionuclide releases to surface waters, wells, or the atmosphere. Doses are calculated for all contributing pathways of exposure, including external exposure, inhalation, and ingestion of contaminated water and foods.

Atmospheric dispersion calculations provide estimates of ground-level air concentrations of radionuclides as a function of distance and direction from the release location. Dispersion factors relating downwind air concentrations to release rates may be entered by the user or calculated by the program. In the latter case, users must supply meteorological data in the form of joint frequency of occurrence of windspeed, wind direction, and atmospheric stability.

For any specified 10,000-year interval, DITTY calculates the average release for each of 143 successive 70-year periods (human lifetimes). The activity present for each 70-year period is calculated as the sum of the material released during that period (uniformly released over 70 years) plus the residual material in the environment from releases in previous periods.

Assumptions and/or Limitations

The following assumptions have been incorporated in the DITTY program:

- A straight-line crosswind-averaged Gaussian plume model is used to provide estimates of ground-level air concentrations of released radioactivity as a function of distance and direction from the release location.
- The calculation of dispersion factors (crosswind-integrated normalized air concentrations) assumes that the joint frequency data describe the directional dependence of downwind transport, and that transport is uniform across each sector and in a straight line from the release point to the location of interest.

- Radionuclide release-rate data are interpolated and integrated to give the total averaged activity for each 70-year period.
- The effect of climatic change on calculations of population exposure is not considered.
- A constant factor (10^{-9} m^{-1}) is assumed in calculating radionuclide activity from resuspended soil. Downwind transport of resuspended activity is not considered.
- A constant sediment deposition factor (25300 $L/m^2/yr$) is assumed based on historical measurements of radionuclides in water and sediment samples from the Columbia River.
- The concentrations of ^3H and ^{14}C in the carbon and hydrogen of environmental media (soil, plants, and animal products) are assumed to have the same specific activity as in the contaminating medium (air or water). The fractional content of hydrogen or carbon in a plant or animal product is then used to compute the concentration of ^3H or ^{14}C in the food product under consideration. It is assumed that plants obtain all their carbon from irrigation water and that animals obtain all their carbon from the ingestion of plants.

Programming Considerations

DITTY is written in FORTRAN-77 and versions are available that run on either VAX 780 or IBM Personal Computers.

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Source

Napier, B. A., R. A. Peloquin, and D. L. Strenge. 1986. DITTY-A Computer Program for Calculating Population Dose Integrated over Ten Thousand Years. PNL-4456, Pacific Northwest Laboratory, Richland, Washington.

FOOD

FOOD and its companion program ARRRG (Appendix B) provide rapid estimates of the radiation dose and dose commitment to man resulting from radioactive materials released to the environment. FOOD was written to address terrestrial exposure pathways and can compute doses from external exposure and for up to 14 crop or animal product pathways. Radiation doses may be calculated from deposition on farm or garden soil and crops during either an atmospheric or water release of radionuclides. Deposition may be either directly from the air or from irrigation water. The type and amounts of crops grown around the point of release determine which pathways are activated.

The fundamental equations used in the FOOD program are documented in Baker et al. (1976) and Brenchly et al. (1977). The program permits dose calculations for either a maximally exposed individual or for a population. FOOD calculates 1-year dose and dose commitments from any one or combination of radionuclides for which sufficient biological data are available. As many as five of 23 possible organs and/or tissues, and mixtures of up to 100 radionuclides, may be selected for any one exposure scenario.

The output from FOOD consists of 1) radiation dose and dose commitment summaries to all chosen organs listed by exposure pathway and by radionuclide, 2) complete listing of dose contributions by radionuclide for each pathway (optional), and 3) radionuclide concentrations in all ingested plant and animal material.

Assumptions and/or Limitations

The following assumptions have been incorporated in the FOOD program:

- The equations for calculating internal dose and dose commitment are derived from those given by the ICRP for body burdens and MPC of each radionuclide (ICRP 1959). Metabolic parameters for the Reference Man (ICRP 1975) are used.
- Usage parameters (i.e., duration of exposure to external sources of radiation and intake rates of ingested food and water) for the average adult are assumed in population dose calculations.

- The radiation dose from external exposure to contaminated farm fields is calculated assuming an "infinite" flat-plane source model. A factor of two has been included to account for self-shielding by surface roughness.

- Airborne radionuclides are deposited onto plant foliage and soil assuming a constant deposition velocity. In cases involving irrigation, sprinkler irrigation is assumed if site-specific data are lacking. This results in a higher radionuclide concentration in plants (and in the animals consuming them) than for trickle or surface irrigation systems. An option in the program (setting the foliar retention factor to zero) allows for the simulation of surface irrigation systems.

- The concentrations of ^{3}H and ^{14}C in the carbon and hydrogen of environmental media (soil, plants, and animal products) are assumed to have the same specific activity as in the contaminating medium (air or water). The fractional content of hydrogen or carbon in a plant or animal product is then used to compute the concentration of ^{3}H or ^{14}C in the food product under consideration. It is assumed that plants obtain all their carbon from irrigation water and that animals obtain all their carbon from the ingestion of plants.

- Verification and/or validation studies. A sensitivity analysis of the FOOD model is documented in Zach (1980).

Programming Considerations

FOOD is written in ASCII FORTRAN and runs on UNIVAC 1100/44 computers. Older versions of the program written in Basic are no longer maintained by PNL.

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Sources

Baker, D. A., G. R. Hoenes, and J. K. Soldat. 1976. FOOD-An Interactive Code to Calculate Internal Radiation Doses from Contaminated Food Products. BNWL-5523, Pacific Northwest Laboratory, Richland, Washington.

Brenchly, D. L., J. K. Soldat, J. A. McNeese, and E. C. Watson. 1977. Environmental Assessment Methodology for the Nuclear Fuel Cycle. BNWL-2219, Pacific Northwest Laboratory, Richland, Washington.

Napier, B. A., R. L. Roswell, W. E. Kennedy, Jr., and D. L. Strenge. 1980. ARRRG and FOOD-Computer Programs for Calculating Radiation Dose to Man from Radionuclides in the Environment. PNL-3180, Pacific Northwest Laboratory, Richland, Washington.

Zach, R. 1980. Sensitivity Analysis of the Terrestrial Food Chain Model FOOD III. AECL-6794, Whiteshell Nuclear Research Establishment, Pinawa, Manitoba.

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ISOSHLD

ISOSHLD performs gamma ray shielding calculations for isotope sources in a wide variety of source and shielding configurations. Attenuation calculations are performed by point kernel integration. For most geometries this is accomplished by a Simpson's rule integration. Source strength in uniform or exponential distribution may be calculated by the linked fission-product inventory code RIBD (Radio-Isotope Build-up and Decay) or by other options as desired. Build-up factors are calculated by the code based on the number of mean free paths of material between the source and detector points, the effective atomic number of a particular shield region, and the point isotropic NDA build-up, available as Taylor coefficients in the effective atomic number range of 4-82.

Isotopic decay, material attenuation, build-up factors, and other required basic data have been compiled in external libraries that are linked to the program. Users supply data describing the geometry and material composition of the source and the geometry and material of the shield. Optional modes of data entry are available for solving special problems. A supplement to the original program (Simmons et al. 1967) allows the calculation of dose rates from shielded Bremsstrahlung sources. An updated photon library (Mansius 1969) containing 499 isotopes has also been added to the original program.

Assumptions and/or Limitations

The following assumptions or limitations apply to the ISOSHLD program:

- Complex geometries are approximated by combinations of simple geometric shapes.
- Errors may arise when dealing with isotopes or isotopic mixtures with energy yields less than 0.15 MeV or greater than 3.0 MeV.
- ISOSHLD does not contain a neutron attenuation routine.
- Gamma decay schemes have not been measured for all of the isotopes in the program library. Approximately 25% of the 499 isotopes in the library lack either gamma energy or both gamma energy and photon

probability data. It is expected that additions will be made to the library as data become available.

Sources

Engel, R. L., J. Greenborg, and M. M. Hendrickson. 1966. ISOSHLD-A Computer Code for General Purpose Isotope Shielding Analysis. BNWL-236, Pacific Northwest Laboratory, Richland, Washington.

Mansius, C. A. 1969. A Revised Photon Probability Library for Use with ISOSHLD III. BNWL-236, Supplement 2, Pacific Northwest Laboratory, Richland, Washington.

Simmons, G. L., J. J. Regimbal, J. Greenborg, E. L. Kelley, Jr., and H. H. Van Tuyl. 1967. ISOSHLD II-Code Revision to Include Calculation of Dose Rate from Shielded Bremsstrahlung Sources. BNWL-236, Supplement 1, Pacific Northwest Laboratory, Richland, Washington.

KRONIC

KRONIC calculates average annual external beta and gamma doses from chronic atmospheric releases of radionuclides. External total-body tissue dose is calculated as a function of 1) gamma and beta particles emitted from the radionuclides present, 2) physical properties describing interactions of gamma and beta particles with air and tissue, 3) the time dependence of fission product concentration, and 4) meteorological conditions at a particular site.

Atmospheric dispersion effects are estimated using data on joint frequency of occurrence of wind speed, wind direction, and stability for a particular site. Each sector is considered to be a plume for which the centerline ground-level dose is calculated for specified downwind distances. Beta dose contributions are calculated using a semi-infinite cloud model. The gamma dose contribution is determined using precalculated factors representing a space integration over the plume volume. An auxiliary program is available with KRONIC for evaluating the plume integrals.

Output from KRONIC consists of a table of annual dose rates reported as a function of direction and distance from the release point.

Assumptions and/or Limitations

The following assumptions are made in calculating radionuclide concentrations in plumes:

- Diffusion along the direction of cloud travel is ignored.
- Vertical cross-wind concentration is normally distributed and the standard deviation is a function of atmospheric stability and distance from the release point. In some dispersion models, this standard deviation is wind-speed dependent.
- The dose receptor is at ground level.
- Cloud depletion by fallout, washout, and rainout can be described by a factor dependent on the distance of travel and is independent of travel time and displacement from the centerline.

- The contribution to dose from radionuclides at distances greater than ± 800 m (from the exposure location) in the direction of cloud travel are ignored.
- A radioactive decay factor is calculated for each radionuclide based on travel time to the exposure point.

Programming Considerations

KRONIC is written in FORTRAN IV and runs on UNIVAC 1108 computers.

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Source

Strenge, D. L., and E. C. Watson. 1973. KRONIC-A Computer Program for Calculating Annual Average External Doses from Chronic Atmospheric Releases of Radionuclides. BNWL-B-264, Pacific Northwest Laboratory, Richland, Washington.

ONSITE/MAXI1

The ONSITE/MAXI1 program was originally developed for use by the U.S. Nuclear Regulatory Commission (NRC) Waste Management staff in conducting human intrusion, dose-pathway analyses for onsite burial of low-activity radioactive wastes. The program activates specific human intrusion scenarios that consider various potential combinations of direct exposure to penetrating radiation, inhalation of airborne radionuclides, ingestion of agricultural products raised in contaminated soil, and ingestion of radionuclides in drinking water.

The VAX and CDC versions of the ONSITE/MAXI1 software package contain four computer codes. ONSITE is an interactive user interface that allows the end-user to create and use the radiation exposure scenarios. MAXI1 uses the scenario information to calculate the maximum annual dose to the exposed individual from selected pathways. Doses from inhalation of airborne radionuclides are estimated using dose conversion factors from the program DACRIN (Appendix B). MAXI2 generates intermediate dose conversion factors for terrestrial food pathways (deposition on farm or garden soil and crops) and calculates external dose rate factors for exposure to soil surface contamination. MAXI3 calculates the data files containing intermediate dose conversion factors for drinking-water and aquatic food pathways. In the personal computer version of ONSITE/MAXI1, MAXI2 and MAXI3 have been incorporated into the program rather than being included as separate modules.

Assumptions and/or Limitations

The exposure scenarios used in ONSITE/MAXI1 are based on user-created "reference environments" that define the agricultural and water-usage practices for a particular geographic area and the general lifestyle (i.e., dietary and recreational habits) characteristics of a hypothetical intruder/resident. Users are given the option of either running default scenarios contained within the program, or entering their own baseline data to generate unique scenarios for specific applications. The following general assumptions and/or limitations apply to the ONSITE/MAXI1 program:

- Dose calculations for external exposure assume that radioactive wastes are located on the surface of the ground, buried at 0.5- and 1.0-m depths, or stored in a room-type structure.
- The personal computer (IBM PC/XT/AT) version of ONSITE/MAXI1 uses radiation dose factors obtained from ICRP Publication 30 (ICRP 1979-1982). The VAX 11/780 and CDC 6600-7600 versions use dose factors from ICRP Publication 2 (ICRP 1959).
- Inhalation dose calculations in the VAX and CDC versions use conversion factors derived from ICRP Publication 2 and the Task Group Lung Model (ICRP 1966) contained in DACRIN (Appendix B). Additional metabolic data for the inhalation calculations are obtained from ICRP Publication 19 (ICRP 1972).
- Dose calculations for inhalation and ingestion exposures use default parameters from Regulatory Guide 1.109 (NRC 1977) to define the reference environment (VAX and CDC versions only).
- The external dose conversion factors for various waste disposal geometries and densities are calculated using the ISOSHLD (Appendix B) shielding program.

Programming Considerations

ONSITE/MAXI1 is written in FORTRAN-77 and versions are available which operate on VAX 11/780 (Kennedy et al. 1986), CDC 6600-7600 series (Napier et al. 1984), and IBM PC/XT/AT (Kennedy et al. 1987) computers.

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Sources

Kennedy, W. E., Jr., R. A. Peloquin, B. A. Napier, and S. M. Neuder. 1986. Intruder Dose Pathway Analysis for the Onsite Disposal of Radioactive Wastes: The ONSITE/MAXI1 Computer Program. NUREG/CR-3620 Supplement 1, U.S. Nuclear Regulatory Commission, Washington, D.C.

Kennedy, W. E., Jr., R. A. Peloquin, B. A. Napier, and S. M. Neuder. 1987. Intruder Dose Pathway Analysis for the Onsite Disposal of Radioactive Wastes: The ONSITE/MAXI1 Computer Program. NUREG/CR-3620 Supplement 2, U.S. Nuclear Regulatory Commission, Washington, D.C.

Napier, B. A., R. A. Peloquin, W. E. Kennedy, Jr., and S. M. Neuder. 1984. Intruder Dose Pathway Analysis for the Onsite Disposal of Radioactive Wastes: The ONSITE/MAXI1 Computer Program. NUREG/CR-3620, U.S. Nuclear Regulatory Commission, Washington, D.C.

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PABLM

PABLM calculates internal radiation doses to man from radionuclides in food products and external radiation doses from a range of environmental sources. Exposure pathway analyses include terms for radionuclides deposited on the ground or crops from contaminated air and irrigation water; radionuclides in contaminated drinking water and aquatic foods raised in contaminated water; and radionuclides in bodies of water and sediments where people might fish, boat, or swim.

A total of 19 ingestion pathways (or food products) may be selected with corresponding consumption rates, growing periods, and air or water concentrations and deposition rates. Up to four external exposure pathways may also be selected with corresponding exposure times and soil or water concentrations. The program is designed to calculate accumulated doses to 23 possible body organs or tissues for any one or combination of radionuclides (a maximum of five organs and 100 radionuclides per case is specified).

Doses may be calculated for either a maximally exposed individual or for a population group. The doses calculated are accumulated doses from continuous chronic exposure. A first-year committed dose is calculated as well as an integrated dose for a selected number of years.

Radioactive decay is considered during the release of radionuclides, after they are deposited on plants or on the ground, and during holdup of food after harvest. A chain decay scheme is used that includes branching to account for transitions to and from isomeric states.

The output from PABLM consists of radiation dose summaries for all chosen organs, listed by exposure pathway and by radionuclide. Dose summaries may be chosen for all terrestrial food pathways and all aquatic food pathways.

Assumptions and/or Limitations

The following assumptions have been incorporated in the PABLM program:

- The equations for calculating internal dose and dose commitment are derived from those given by the ICRP for body burdens and MPC of each radionuclide (ICRP 1959). Metabolic parameters for the Reference Man (ICRP 1975) are used.

- Usage parameters (i.e., duration of exposure to external sources of radiation and intake rates of ingested food and water) for the average adult are assumed in population dose calculations.
- Radiation doses from external exposure to contaminated water and soil are calculated by assuming that the contaminated medium is large enough to be considered an "infinite" volume or plane relative to the range of emitted radiations.
- Constant ingestion rates are assumed for food products.
- The concentrations of ^{3}H and ^{14}C in the carbon and hydrogen of environmental media (soil, plants, and animal products) are assumed to have the same specific activity as in the contaminating medium (air or water). The fractional content of carbon or hydrogen in a plant or animal product is then used to compute the concentration of ^{3}H or ^{14}C in the food product under consideration. The model assumes that plants obtain all of their carbon from irrigation water and that animals obtain all of their carbon from ingestion of plants.
- In predicting radionuclide concentrations in the sediments of a river or lake downstream from a nuclear facility, it is assumed that there is a constant water concentration for each year of the release and that deposition rate to the sediment is dependent only on water concentration.
- External doses from radionuclides deposited on farm fields are calculated assuming an infinite flat-plane source model.

<u>Programming Considerations</u>

PABLM is written in ASCII FORTRAN and operates on UNIVAC 1100/44 computers.

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Source

Napier, B. A., W. E. Kennedy, Jr., and J. K. Soldat. 1980. PABLM-A Computer Program to Calculate Accumulated Radiation Doses from Radionuclides in the Environment. PNL-3209, Pacific Northwest Laboratory, Richland, Washington.

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SUBDOSA

SUBDOSA is used to calculate external radiation doses from the accidental atmospheric release of radionuclides. Dose calculations are based on the quantity of radionuclide released, duration of release, atmospheric conditions during release, and horizontal distance from the release point. Both gamma and beta radiation are calculated as a function of depth in tissue, summed and reported as skin, eye, gonadal, and total body dose. The dose from gamma radiation is calculated using a numerical integration technique to account for the finite size of the plume.

Doses are calculated for releases within each of several release time-intervals. Up to six time intervals can be specified and separate nuclide inventories and atmospheric dispersion conditions are considered for each time interval. Radioactive decay is considered during release and/or transit using a chain decay scheme that includes branching to account for transitions to and from isomeric states.

Output from SUBDOSA consists of the normalized air concentrations of radionuclides at ground level, and requested radiation doses listed as a function of distance from the point of release.

Assumptions and/or Limitations

The following assumptions have been incorporated in the SUBDOSA program:

- External dose calculations for the skin, lens of eye, and total body assume tissue depths of 0.007, 0.1 and 5 cm, respectively.
- Radionuclides deposited in the body via inhalation pathways are not considered.
- Diffusion along the direction of cloud travel is ignored.
- Vertical and lateral crosswind concentrations are normally distributed and the standard deviations are a function of atmospheric stability and distance from the release point. In some dispersion models, the standard deviations are wind-speed dependent.
- The dose receptor is at ground level.

- Cloud depletion by fallout, washout, and rainout can be described by a factor dependent on the distance of travel and is independent of travel time and displacement from the centerline.
- The contribution to dose from radionuclides greater than ± 800 m (from the exposure point) in the direction of cloud travel are ignored.
- Radionuclide decay is calculated for each radionuclide based on travel time to the exposure point, and this concentration is used for all downwind integration points about the exposure point.

Programming Considerations

SUBDOSA is written in FORTRAN-77 and versions are available which operate on UNIVAC 1100/44 and VAX 11/780 computers.

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Source

Strenge, D. L., E. C. Watson and J. R. Houston. 1975. SUBDOSA-A Computer Program for Calculating External Doses from Accidental Atmospheric Releases of Radionuclides. BNWL-B-351, Pacific Northwest Laboratory, Richland, Washington.

APPENDIX C

GENERIC ASSUMPTIONS USED IN RADIATION DOSIMETRY MODELS

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TABLE C.1. Organ Masses Used in Radiation Dose Calculations (ICRP 1975)

Organ	Mass (g)
Total body	70,000
Body Water	63,000
Kidney	310
Liver	1,800
Spleen	180
Bone	7,000
Fat	13,500
Lung	1,000
Adrenals	14
Testes	35
Ovaries	11
Skin	2,600
Brain	1,400
Muscle	28,000
Prostate	16
Thyroid	20
Pancreas	100
Heart	330
GI-general(a)	0
GI-stomach(a)	250
GI-small intestine(a)	400
GI-large intestine(a)	250
GI-lower large intestine(a)	135

(a) Masses are for contents of compartment.

TABLE C.2. Generic Fractions and Concentrations of Hydrogen and Carbon in Environmental Media, Vegetation, and Animal Products (Napier, Kennedy, and Soldat 1980)

A. Fractions in Food

Food or Fodder	Water f_w	Carbon (dry) f_c	Hydrogen (dry) f_h	Carbon[a] (wet) F_{cv}, F_{ca}	Hydrogen[b] (wet) F_{hv}, F_{ha}
Fresh Fruits, Vegetables, and Grass	0.80	0.45	0.062	0.090	0.10
Grains and stored Animal Animal Feed	0.12	0.45	0.062	0.40	0.068
Eggs	0.75	0.60	0.092	0.15	0.11
Milk	0.88	0.58	0.083	0.070	0.11
Beef	0.60	0.60	0.094	0.24	0.10
Pork	0.50	0.66	0.10	0.33	0.11
Poultry	0.70	0.67	0.087	0.20	0.10

B. Concentrations in Media

Absolute Humidity............................ 0.008 L/m^3

Concentrations of Carbon in Water..... 2.0×10^{-5} kg/L[c]

Concentrations of Carbon in Air...... 1.6×10^{-4} kg/m^3[d]

Fraction of Soil which is Carbon................... 0.03

Soil Moisture.................................. 0.1 L/kg

(a) F_{cv} or $F_{ca} = f_c(1-f_w)$

(b) F_{hv} or $F_{ha} = f_w/9 + f_h(1-f_w)$

(c) Assumes a typical bicarbonate concentration of 100 mg/L

(d) Assumes a typical atmospheric CO_2 concentration of 320 ppm$_v$

TABLE C.3. Generic Consumption Rates of Feed and Water by Farm Animals (Napier, Kennedy, and Soldat 1980)

	Feed or Forage[a] (kg/day)	Water (L/day)
Milk Cow	55 (fresh forage)	60
Beef Cattle	68 (dry feed)	50
Pig	4.2 (dry feed)	10
Poultry (chickens)	0.12 (dry feed)	0.3

(a) Equivalent fresh weight required to ensure proper calculation of radionuclide intake by animal.

TABLE C.4. Clearance Times for GI Tract Used in Radiation Dose Models (Napier, Kennedy, and Soldat 1980)

Organ	Travel Time through Organ (days)	Travel Time to Organ (days)
Stomach	0.0417[a]	0.0
GI-small intestine	0.1667	0.0417
GI-upper large intestine	0.3333	0.2083
GI-lower large intestine	0.7500	0.5417

(a) Ingested material does not flow through the stomach. It remains in the stomach for 1 hour after which time it is passed to the small intestine.

TABLE C.5. Parameters Used for Calculation of Radiation Dose Factors from Consumption of Foods (McKenzie et al. 1985)

Food	Growing Period (days)	Yield (kg/m^2)	Holdup[a] (days)	Consumption[b] (kg/year)
Leafy vegetables	90	1.5	1	9.5
Other above-ground vegetables	60	0.70	1	9.5
Root vegetables	90	9.0	1	76
Fruit	90	1.7	10	42
Wheat and Grain	90	0.72	10	51
Eggs	90	0.84[c]	2	19
Milk	30	1.3 [c]	2	110
Beef	90	0.84[c]	15	39
Pork	90	0.84[c]	15	29
Poultry	90	0.84[c]	2	8.5

(a) Time between harvest and consumption.
(b) These rates are obtained from Regulatory Guide 1.109 (NRC 1977) and prorated by food category using the fraction of total food consumed by an average individual as calculated from Napier (1981, Table 8).
(c) Yield of animal feeds (i.e., grain or pasture grass).
(d) Units of liters/year.

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HANFORD SITE NATIONAL ENVIRONMENTAL POLICY ACT (NEPA) CHARACTERIZATION

Chapter 6: Statutory and Regulatory Requirements

E. B. Moore

September 1988

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the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Richland, Washington 99352

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6.0 STATUTORY AND REGULATORY REQUIREMENTS

The Hanford Site is owned by the U.S. Government and is managed by the U.S. Department of Energy (DOE). It is the policy of DOE to carry out its operations in compliance with all applicable federal laws and regulations, state laws and regulations, presidential executive orders, and DOE orders. Significant environmental laws and regulations are discussed in this chapter.

[The following introduction (italicized text) is intended to be explanatory to people writing a Chapter 6.0 for a Hanford Site EIS but is not intended to be included in the EIS.]

INTRODUCTION

The regulations of the Council on Environmental Quality (CEQ) in the Code of Federal Regulations (CFR) at 40 CFR 1500-1508 implement the National Environmental Policy Act (NEPA) and set forth requirements for the preparation of environmental documentation by federal agencies. The CEQ regulations implement the NEPA process and focus on the environmental impact statement (EIS). The regulations 1) identify the types of actions proposed by a federal agency that require preparation of an EIS, 2) prescribe the content of an EIS, and 3) identify actions and other environmental reviews that must be undertaken by the federal agency in preparing and circulating an EIS.

A specific requirement in the CEQ regulations (40 CFR 1502.25) is that the EIS must list "all Federal permits, licenses, and other entitlements which must be obtained in implementing the proposal." There is, however, no requirement in the CEQ regulations that the EIS must list or discuss applicable environmental statutes and regulations. Nevertheless, applicable environmental statutes and regulations have been discussed in recent Hanford Site EISs; and Chapter 6.0 of these EISs has evolved into a chapter on "Statutory and Regulatory Requirements." Given the large number of applicable environmental regulations and the rapidly changing character of environmental regulation, this practice is likely to continue.

The purpose, then, of this document is to present a "reference" Chapter 6.0 that can be used in the preparation of future Hanford Site EISs. The intent here is to present a rather inclusive discussion of federal environmental laws, regulations, and permits that are applicable to activities at the Hanford Site. The information in this chapter car then be adapted to any future Hanford Site EIS simply by deleting the irrelevant parts and by adding some specificity with respect to the action. It is also intended that this document be revised on a regular basis because of the rapidly changing character of federal environmental law and regulation, particularly the environmental regulation of one federal agency by another, and because of the rapidly emerging (and thus still not fully developed) regulation of federal facilities by states. State laws and regulations pertaining to the environmental regulation of federal facilities are not presented in this document for the above reason but will be added at a later date as their specific applicability becomes clear.

It should be noted that environmental standards and permit requirements usually appear in regulations and not in the laws themselves. Thus, more emphasis is placed on regulations and less on laws in this document.

ORDER OF PRECEDENCE OF FEDERAL AND STATE ENVIRONMENTAL LAWS AND REGULATIONS

Environmental regulation of federal facilities is governed by federal law. Most major federal environmental laws now include provision for regulation of federal activities that impact the environment. The activity to be regulated is usually an activity being carried out by an agency of the executive branch. The environmental law will also designate a specific agency, such as the U.S. Environmental Protection Agency (EPA) or the U.S. Nuclear Regulatory Commission (NRC), as the regulator, or the law will permit self-regulation. In addition, federal law may provide for delegation of the environmental regulation of federal facilities to the states (delegation). Or federal law may provide outright authority to the states to regulate federal facilities (waiver of sovereign immunity). At Hanford, all three situations apply in varying degrees: the EPA has regulatory authority over all Hanford facilities (where not waived or delegated) and the NRC may have regulatory authority over some future Hanford facilities; the EPA shares regulatory authority with, or is in the process of delegating regulatory authority to, the State of Washington; and the State of Washington is in the process of asserting its own independent regulatory authority under waivers of sovereign immunity.

At the top of the hierarchy of environmental regulation of federal facilities is federal law. Next are federal regulations that appear in the CFR. These regulations have been promulgated according to the requirements of the Administrative Procedure Act and have the full force and effect of the federal laws from which they derive. State statutes, or portions of state statutes, that have been enacted in accordance with waivers of sovereign immunity or in accordance with delegated authority also have the full force and effect of the federal law or regulation from which they derive. Similarly, state regulations, which have been promulgated in accordance with appropriate state administrative procedures and in accordance with delegated authority or waivers of sovereign immunity, also have the force and effect of the law or regulation from which they derive. At the bottom of the hierarchy, and without much legal effect (from the point of view of legally enforcing environmental compliance), are DOE Orders and other guidelines that have not been promulgated under the federal Administrative Procedure Act or under an equivalent state statute.

As a practical matter at Hanford, federal environmental standards must be met, and state standards must be met when they flow from delegated authority or from waivers of sovereign immunity. As a legal matter, differences in language and in interpretation between federal law and the pursuant state laws and regulations will result in disagreements and in lawsuits. These prospective events, however, need not concern us here.

CITATION OF LAWS AND REGULATIONS

Laws and regulations may be cited both by their name and by their location in the appropriate reference. Federal laws are most often cited as a public law (Pub.L. or PL) or by their location in the United States Code (U.S.C. or USC). Section numbers differ between the two, so it must be understood which is being cited. Federal regulations appear in the CFR. Washington State laws are most often cited by their location in the Revised

Code of Washington (RCW), and Washington State regulations are cited by their location in the Washington Administrative Code (WAC). Announcements of proposed and final federal regulations appear in the Federal Register (FR). Announcements of proposed and final Washington State regulations appear in the Washington State Register (WSR).

SPECIFIC FEDERAL LAWS CITED IN THE CEQ REGULATIONS

Four federal laws are specifically cited in the CEQ regulations and deserve mention here. These are Section 309 of the Clean Air Act (42 U.S.C. 7609), the Fish and Wildlife Coordination Act (16 U.S.C. 661 et seq.), the National Historic Preservation Act (16 U.S.C. 470 et seq.), and the Endangered Species Act (16 U.S.C. 1531 et seq.). Section 309 of the Clean Air Act directs the EPA to review and comment on the environmental impacts of federal activities, including actions for which EISs are prepared. In addition to commenting, EPA rates every draft EIS prepared by a federal agency. EPA's comments are answered in the final EIS, but the EPA rating is usually not mentioned in an EIS. This latter fact should be known by the EIS preparers so that the EIS will be prepared in such a fashion as to avoid an unfavorable rating. The other three federal laws are often discussed in the chapter on the affected environment, rather than in the chapter on statutory and regulatory requirements. They should be discussed somewhere in the EIS and are discussed here for completeness.

6.1 FEDERAL ENVIRONMENTAL LAWS

Significant federal environmental laws applicable to the Hanford Site include the following:

- National Environmental Policy Act (NEPA) (42 U.S.C. 4321 et seq.)
- Clean Air Act (CAA) (42 U.S.C. 7401 et seq.)
- Clean Water Act (CWA) (33 U.S.C. 1251 et seq.)
- Safe Drinking Water Act (SDWA) (42 U.S.C. 300f et seq.)
- Resource Conservation and Recovery Act (RCRA) (42 U.S.C. 6901 et seq.)

- Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) as amended by the Superfund Amendments and Reauthorization Act (SARA) (42 U.S.C. 9601 et seq.).

Other federal environmental laws applicable to the Hanford Site include the following:

- Endangered Species Act (16 U.S.C. 1531-1534)
- Fish and Wildlife Coordination Act (16 U.S.C. 661-666c)
- Bald and Golden Eagle Protection Act (16 U.S.C 668-668d)
- Migratory Bird Treaty Act (16 U.S.C 703-711)
- National Historic Preservation Act (16 U.S.C. 470-470w-6)
- Archaeological Resources Protection Act (16 U.S.C. 470aa-470ll)
- Archaeological and Historic Preservation Act (16 U.S.C. 469-469c)
- American Antiquities Act (16 U.S.C. 431-433)
- American Indian Religious Freedom Act (42 U.S.C. 1996).

The Atomic Energy Act (AEA) (42 U.S.C. 2011 et seq.), the Low-Level Radioactive Waste Policy Act (LLWPA) (42 U.S.C. 2021b et seq.), and the Nuclear Waste Policy Act (NWPA) (42 U.S.C. 10101 et seq.) should also be included in these lists, although they are not environmental laws per se. They are included here because environmental protection regulations applicable to the Hanford Site have been promulgated under their authority.

6.2 EPA REGULATIONS

EPA regulations that apply to DOE operations at the Hanford Site have been promulgated under the NEPA, CAA, CWA, SDWA, RCRA, CERCLA, SARA, AEA, LLWPA, NWPA, and other federal statutes. Several of the more important of these regulations are listed below:

- 40 CFR 60, "Standards of Performance for New Stationary Sources." EPA regulations in 40 CFR 60 provide standards for the control of the emission of pollutants to the atmosphere. Construction or modification of an emissions source may require a prevention of significant deterioration of air quality (PSD) permit under 40 CFR 52.

- 40 CFR 61, "National Emission Standards for Hazardous Air Pollutants," also 40 CFR 61 Subpart H, "National Emission Standards for Radionuclide Emissions from Department of Energy Facilities." EPA hazardous emission standards in 40 CFR 61 provide for the control of the emission of hazardous pollutants to the atmosphere, and 40 CFR 61 Subpart H applies specifically to the emission of radionuclides from DOE facilities. Approval to construct a new facility or to modify an existing one may be required by these regulations.

- 40 CFR 122, "The National Pollutant Discharge Elimination System" (NPDES). EPA regulations in 40 CFR 122 apply to the discharge of pollutants into waters of the United States. NPDES permits may be required by these regulations.

- 40 CFR 141, "National Interim Primary Drinking Water Regulations." EPA drinking water standards in 40 CFR 141 apply to Columbia River water at community water supply intakes downstream of the Hanford Site.

- 40 CFR 191, "Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes." EPA regulations in 40 CFR 191 provide environmental standards for the management, storage, and disposal of spent nuclear fuel, high-level radioactive wastes, and transuranic radioactive wastes.

- 40 CFR 193, "Environmental Radiation Protection Standards for Management and Land Disposal of Low-Level Radioactive Wastes." EPA environmental radiation protection standards for low-level radioactive waste disposal in 40 CFR 193 will apply, when promulgated by the EPA, to the disposal of low-level radioactive waste owned by

DOE. At present, however, only an advance notice of proposed rule making has been published by the EPA, and no draft standards are available for review.

- 40 CFR 260-267 and 270-271, "Hazardous Waste Management." EPA regulations in 40 CFR 260-267 and 270-271 apply to the treatment, transport, storage, and disposal of hazardous wastes owned by DOE, including the hazardous component of mixed radioactive and hazardous wastes. "RCRA" permits may be required by these regulations.

- 40 CFR 300, "National Oil and Hazardous Substances Pollution Contingency Plan." EPA regulations in 40 CFR 300 apply to the release of hazardous substances into the environment from sites or facilities covered by CERCLA, which for the most part are retired sites and facilities. Under its CERCLA/SARA responsibilities, the DOE is completing characterization of disposal sites at Hanford that may contain hazardous wastes.

6.3 OTHER FEDERAL REGULATIONS

- 10 CFR 1022, "Compliance with Floodplain/Wetlands Environmental Review Requirements." DOE regulations in 10 CFR 1022 apply to DOE activities that are proposed to take place either in wetlands or in floodplains.

- 36 CFR 800, 25 CFR 261, 43 CFR 3, and 43 CFR 7, Historic preservation regulations. Requirements of the National Historic Preservation Act in 36 CFR 800, the American Antiquities Act in 25 CFR 261 and 43 CFR 3, and the Archaeological Resources Protection Act and the American Indian Religious Freedom Act in 43 CFR 7 apply to the protection of historic and cultural properties, including both existing properties and those discovered during construction.

- 40 CFR 1500-1508, Regulations of the Council on Environmental Quality (CEQ) that implement NEPA. The CEQ regulations in 40 CFR 1500-1508 provide for the preparation of environmental documentation on any federal action impacting the environment, and require federal agencies to prepare an environmental impact statement (EIS) on any federal action significantly affecting the quality of the human environment.

- 49 CFR 171-179, "Hazardous Materials Regulations." Department of Transportation regulations in 49 CFR 171-179 apply to the handling, packaging, labeling, and shipment of hazardous materials, including radioactive wastes. DOE Order 5480.1A specifically incorporates 49 CFR 171-179 by reference.
- 50 CFR 10-24 and 50 CFR 402, Species protection regulations. Regulations of the Endangered Species Act, the Bald and Golden Eagle Protection Act, and the Migratory Bird Treaty Act in 50 CFR 10-24 and 50 CFR 402 apply to the protection of these species on the Hanford Site.

6.4 STATE LAWS AND REGULATIONS

Activities of the federal government are ordinarily not subject to regulation by the states, unless specific exceptions are created by Congress. Exceptions with respect to environmental regulation have been created by Congress and provisions in several federal laws give to the states specific authority to regulate federal environmental activities. This regulation may be either by delegation or by waiver of sovereign immunity. Waivers (or partial waivers) of sovereign immunity appear in Section 118 of the CAA, Section 313 of the CWA, Section 1447 of the SDWA, Section 6001 of RCRA, and Section 120 of CERCLA/SARA. At the present time, Washington State programs with respect to the environmental regulation of Hanford facilities are coordinated with EPA Region 10.

Washington State statutes and regulations potentially applicable to the environmental regulation of federal activities at Hanford under federal waivers of sovereign immunity include: (To be added at a later date).

6.5 DOE ORDERS

The most significant DOE order with respect to environmental compliance at Hanford is DOE Order 5480.1A. This order was cancelled on September 23, 1986, and replaced by DOE Order 5480.1B, "Environment, Safety, and Health Program for Department of Energy Operations," except that individual chapters of DOE Order 5480.1A remain in effect until replaced by DOE Orders 5480.2 through 5480.13. These orders cover environmental protection, safety, and health protection standards; hazardous and radioactive mixed waste management; safety requirements for the packaging of radioactive materials; safety of nuclear facilities; radiation protection; prevention, control, and abatement of environmental pollution; and other standards for the safety and protection of workers and the public. Regulations and standards of other federal agencies and regulatory bodies, as well as other DOE orders, are incorporated by reference into the DOE Order 5480 series.

Other DOE orders that are important with respect to environmental compliance include DOE Order 5820.2, "Radioactive Waste Management."

6.6 PERMITS

The DOE holds a NPDES permit from EPA Region 10 for the discharge of nonradioactive liquids to the Columbia River. On June 28, 1985, the DOE applied for renewal of this permit. On August 21, 1987, the DOE also applied for an alternative limitation on thermal effluents from the N Reactor (CWA Section 316(a) variance).

The DOE holds a PSD permit from EPA Region 10 for the discharge of oxides of nitrogen to the atmosphere from the PUREX and Uranium Oxide Plants.

On November 6, 1985, the DOE submitted a RCRA Part B application to EPA Region 10 and to the Washington Department of Ecology for the storage, treatment, and disposal of hazardous wastes at Hanford.

On July 7, 1987, DOE submitted an application to the Washington State Department of Ecology (WDOE) as a matter of comity for water withdrawal rights from the Columbia River for site characterization activities related to the Basalt Waste Isolation Project. On October 23, 1987, WDOE granted a temporary permit to DOE.

6.7 RADIATION STANDARD FOR PROTECTION OF THE PUBLIC

Numerical standards for protection of the public from releases of radioactivity have been set by the EPA and appear in 40 CFR 61 and 40 CFR 141. The standards in 40 CFR 61.102 apply to releases of radionuclides to the atmosphere from DOE facilities and state that:

> Emissions of radionuclides to air from [DOE] facilities...shall not exceed those amounts that cause a dose equivalent of 25 mrem/y to the whole body or 75 mrem/y to the critical organ of any member of the public. Doses due to radon-220, radon-222, and their respective decay products are excluded from these limits.

The standards in 40 CFR 141.16 apply to releases of radionuclides from DOE facilities (and also non-DOE facilities) as they impact community water systems and state that:

> The average annual concentration of beta particle and photon radioactivity from man-made radionuclides in drinking water shall not produce an annual dose equivalent to the body or any internal organ greater than 4 millirem/year.

Also, maximum contaminant levels in community water systems of 5 picocuries per liter of combined radium-226 and radium-228, and maximum contaminant levels of 15 picocuries per liter of gross alpha particle activity, including radium-226 but excluding radon and uranium, are specified in 40 CFR 141. 40 CFR 141 also specifies maximum concentrations of some chemical containments.

EPA regulations in 40 CFR 193, "Environmental Radiation Protection Standards for Management and Land Disposal of Low-Level Radioactive Wastes," when promulgated will also contain numerical standards for protection of the public from releases of radioactivity from low-level radioactive waste management and disposal activities.

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